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ABSTRACT

This individualized learning module on intermediate oscillators is one in a series of modules for a course in basic electricity and electronics. The course is one of a number of military-developed curriculum packages selected for adaptation to vocational instructional and curriculum development in a civilian setting. Five lessons are included in the module: (1) Hartley Oscillators, (2) Resistive Capacitive Phase Shift Oscillators, (2) Wien-Bridge Oscillators, (4) Blocking Oscillators, and (5) Crystal Controlled Oscillators. Each lesson follows a typical format including a lesson overview, a list of study resources, the lesson content, a programmed instruction section, and a lesson summary. (Progress checks and other supplementary material are provided for each lesson in a student's guide, CE 026 590.) (LRA)

ED190906

CHIEF OF NAVAL EDUCATION AND TRAINING

CNTT-E-054

JULY 1980

Military Curricula for Vocational & Technical Education

BASIC ELECTRICITY AND ELECTRONICS.

MODULE 32. INTERMEDIATE OSCILLATORS.

STUDY BOOKLET.

CE 026 591

THE NATIONAL CENTER FOR RESEARCH IN VOCATIONAL EDUCATION
THE OHIO STATE UNIVERSITY

MILITARY CURRICULUM MATERIALS

The military-developed curriculum materials in this course package were selected by the National Center for Research in Vocational Education Military Curriculum Project for dissemination to the six regional Curriculum Coordination Centers and other instructional materials agencies. The purpose of disseminating these courses was to make curriculum materials developed by the military more accessible to vocational educators in the civilian setting.

The course materials were acquired, evaluated by project staff and practitioners in the field, and prepared for dissemination. Materials which were specific to the military were deleted, copyrighted materials were either omitted or approval for their use was obtained. These course packages contain curriculum resource materials which can be adapted to support vocational instruction and curriculum development.

Military Curriculum Materials Dissemination Is . . .

an activity to increase the accessibility of military-developed curriculum materials to vocational and technical educators.

This project, funded by the U.S. Office of Education, includes the identification and acquisition of curriculum materials in print form from the Coast Guard, Air Force, Army, Marine Corps and Navy.

Access to military curriculum materials is provided through a "Joint Memorandum of Understanding" between the U.S. Office of Education and the Department of Defense.

The acquired materials are reviewed by staff and subject matter specialists, and courses deemed applicable to vocational and technical education are selected for dissemination.

The National Center for Research in Vocational Education the U.S. Office of Education's designa ı representative to acquire the materials and conduct the project activities.

Project Staff:

Wesley E. Budke, Ph.D., Director
National Center Clearinghouse

Shirley A. Chase, Ph.D.
Project Director

What Materials Are Available?

One hundred twenty courses on microfiche (thirteen in paper form) and descriptions of each have been provided to the vocational Curriculum Coordination Centers and other instructional materials agencies for dissemination.

Course materials include programmed instruction, curriculum outlines, instructor guides, student workbooks and technical manuals.

The 120 courses represent the following sixteen vocational subject areas:

Agriculture	Food Service
Aviation	Health
Building & Construction Trades	Heating & Air Conditioning
Clerical Occupations	Machine Shop
Communications	Management & Supervision
Drafting	Meteorology & Navigation
Electronics	Photography
Engine Mechanics	Public Service

The number of courses and the subject areas represented will expand as additional materials with application to vocational and technical education are identified and selected for dissemination.

How Can These Materials Be Obtained?

Contact the Curriculum Coordination Center in your region for information on obtaining materials (e.g., availability and cost). They will respond to your request directly or refer you to an instructional materials agency closer to you.

CURRICULUM COORDINATION CENTERS

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Springfield, IL 62777
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- Generating knowledge through research
- Developing educational programs and products
- Evaluating individual program needs and outcomes
- Installing educational programs and products
- Operating information systems and services
- Conducting leadership development and training programs

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Military Curriculum Materials for Vocational and Technical Education

Information and Field Services Division

The National Center for Research in Vocational Education

OVERVIEW
BASIC ELECTRICITY AND ELECTRONICS
MODULE 32

Intermediate Oscillators

In this module you will learn about several different types of oscillators. You will learn how oscillator output frequencies are determined, maintained, and how the oscillator circuit converts DC to AC. You will learn about regenerative feedback and how it is used to sustain oscillation. Also you will become familiar with the circuit configurations of the various types of oscillators and their special use. Besides learning about oscillators which produce sinusoidal outputs, you will learn about oscillators which provide other output waveforms.

This module has been divided into five lessons:

Lesson 1 Hartley Oscillators
Lesson 2 RC Phase Shift Oscillators
Lesson 3 Wien-Bridge Oscillators
Lesson 4 Blocking Oscillators
Lesson 5 Crystal Controlled Oscillators

PREPARED FOR

BASIC ELECTRICITY AND ELECTRONICS

CANTRAC A-100-0010,

MODULE THIRTY TWO

INTERMEDIATE OSCILLATORS

PREPARED BY

NAVAL EDUCATION AND TRAINING PROGRAM

DEVELOPMENT CENTER DETACHMENT

GREAT LAKES NAVAL TRAINING CENTER

. GREAT LAKES, ILLINOIS 60088

JULY 1980

OVERVIEW
LESSON 1

Hartley Oscillators

In this lesson you will learn about Hartley oscillators and their application in electronics equipment. You will learn to identify schematics for series and shunt-fed Hartley oscillators, and become familiar with operation of these circuits. You will learn to trace current flow in Hartley oscillator circuits and learn about possible applications for this type of signal source.

The learning objectives of this lesson are as follows:

TERMINAL OBJECTIVE(S):

32.1.56 When the student completes this lesson (s)he will be able to IDENTIFY the schematic diagrams, component functions, and operational principles of series-fed and shunt-fed Hartley oscillator circuits, including the accomplishment of phase shift action, by selecting statements from a choice of four. 100% accuracy is required.

ENABLING OBJECTIVE(S):

When the student completes this lesson, (s)he will be able to:

32.1.56.1 IDENTIFY the functions of an LC oscillator and its three sections by selecting the correct statement from a choice of four. 100% accuracy is required.

32.1.56.2 IDENTIFY the operating characteristics of Class A and Class C oscillator circuits by selecting the correct statement from a choice of four. 100% accuracy is required.

32.1.56.3 IDENTIFY the advantages of a Hartley oscillator by selecting the correct description of its characteristics from a choice of four. 100% accuracy is required.

32.1.56.4 IDENTIFY the factors necessary to accomplish phase-shift action in a Hartley oscillator circuit by selecting the correct statement from a choice of four. 100% accuracy is required.

32.1.56.5 IDENTIFY the function of components and circuit operation of series-fed and shunt-fed Hartley oscillator circuits, given a schematic diagram, by selecting the correct statement from a choice of four. 100% accuracy is required.

32.1.56.6 IDENTIFY the schematic diagrams of series-fed and shunt-fed Hartley oscillators by selecting the correct name(s) from a choice of four. 100% accuracy is required.

32.1.56.7 MEASURE and COMPARE the output frequency of Hartley oscillator circuits, given a training device, circuit boards, test equipment and proper tools, schematic diagrams, and a job program containing reference data for comparison. Recorded data must be within limits stated in the job program.

BEFORE YOU START THIS LESSON, READ THE LESSON LEARNING OBJECTIVES AND PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

BASIC ELECTRICITY AND ELECTRONICS

MODULE THIRTY TWO

LESSON 1

HARTLEY OSCILLATORS

SUMMARY
LESSON 1

Hartley Oscillators

This lesson explains the operation of the Hartley oscillator, a type of oscillator commonly used in electronic equipments. One application for this oscillator is providing frequency injection for the mixer stage of a superheterodyne radio receiver. When the oscillator is used in this way it is called a local oscillator (LO). The Hartley circuit is also used to provide a variable frequency in radio transmitters and signal generators.

There are two types of basic Hartley oscillators...series and shunt.. Both of these oscillators are discussed in subsequent paragraphs and comparable AC circuit schematics are provided. The major advantage of a Hartley type oscillator is that it provides good frequency stability over a wide range of frequencies and produces a constant amplitude sine wave output.

Recall that one of the requirements of any oscillator is the necessity for an in-phase regenerative feedback voltage. In order to assure that the regenerative feedback is in phase with the input of the amplifying device, it is necessary to effect a 360 degree phase shift within the oscillator circuit. This is discussed in detail in subsequent paragraphs relating specifically to the Hartley oscillator.

Remember that the function of an oscillator is to produce a constant amplitude stable output signal. Recall also that unless the feedback is regenerative, oscillations cannot be sustained. Since the purpose of feedback is to compensate for internal power loss, it is obvious that when the feedback is exactly in phase, less feedback is necessary to overcome circuit losses. A difference of a few degrees in the phase of the feedback either way still enables the circuit to oscillate. The amplitude of the necessary feedback required to sustain oscillation, of course, is much less when the feedback is exactly in phase. The schematic diagram shown in Figure 1 is the AC equivalent of a Hartley type oscillator.

$$f_o = \frac{1}{2\pi\sqrt{L_t C_t}}$$

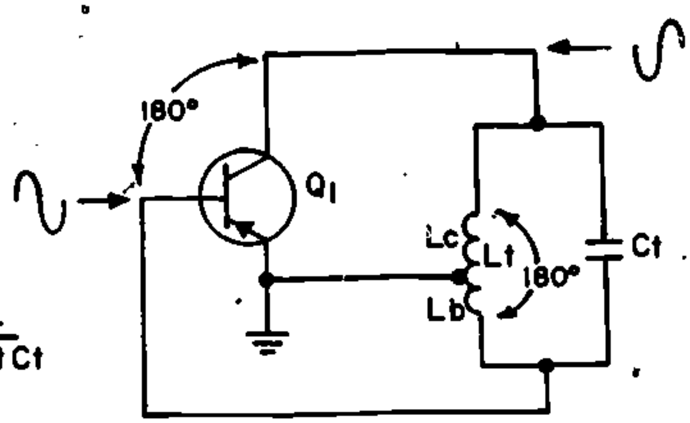


Figure 1

AC EQUIVALENT-HARTLEY OSCILLATOR

LIST OF STUDY RESOURCES
LESSON 1

Hartley Oscillators

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following study resources:

Written Lesson presentation in:

Module Booklet:

- Summary
- Programmed Instruction
- Narrative

Student's Guide:

- Summary
- Progress Check
- Job Program Thirty Two-1, "Hartley Oscillators"

Additional Material(s):

Enrichment Material(s):

Electronics Installation and Maintenance Book, EIMB, (Electronic Circuits) NAVSHIPS 0967-000-0120

YOU MAY USE ANY, OR ALL, RESOURCES LISTED ABOVE, INCLUDING THE LEARNING CENTER INSTRUCTOR: HOWEVER, ALL MATERIALS LISTED ARE NOT NECESSARILY REQUIRED TO ACHIEVE LESSON OBJECTIVES. THE PROGRESS CHECK MAY BE TAKEN AT ANY TIME.

oscillating. Study the Hartley schematic shown in the Figure and notice that the primary of the transformer is designated as L_c and the secondary section of the transformer is designated as L_b. Although these coils have a common point, mutual coupling still exists between them. Current which flows through L_c induces a voltage across L_b and produces transformer coupling action comparable to the transformer coupling action of the Armstrong circuit. This type of coupling action is often referred to as an "autotransformer action".

Remember that the two major classifications of Hartley oscillators are series and shunt fed oscillators. Recall also that one of the characteristics of all oscillators is that the amplifier section of the oscillator must be forward biased in order to provide amplification. The schematic shown in Figure 3 is that of a series-fed Hartley oscillator circuit.

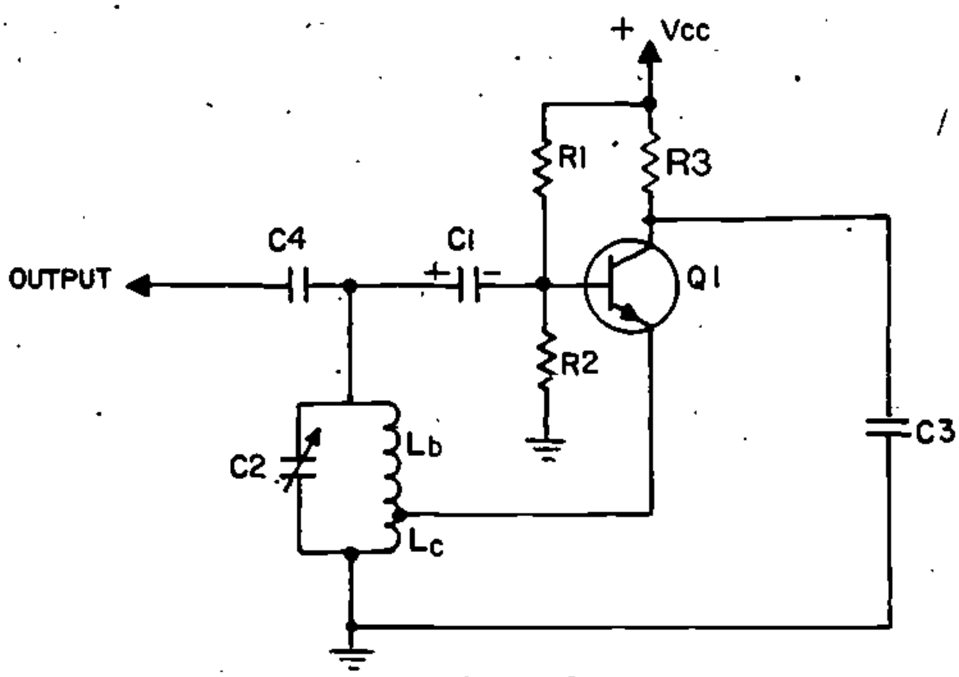


Figure 3

SERIES FED HARTLEY OSCILLATOR

Examine the schematic and notice that resistors R1 and R2 provide the forward bias for Q1. Current flowing from ground to VCC places the forward bias of Q1 at approximately 0.6 volt positive. Remember that a forward bias is necessary in order for the transistor to conduct and oscillation to begin. Transistor current then flows from ground through the tank coil L_c, Q1, R3 and then back to VCC. This creates a magnetic field around coil L_c which induces a voltage into coil L_b. The polarity of the voltage across L_b causes the forward bias of the transistor to increase, as does the conduction of the transistor. Transistor conduction then follows the voltage across the tank. At the same time, the induced voltage in L_b and L_c start oscillations in the tank circuit. The alternate charging and discharging of C2 causes an exchange of energy from the capacitor's electric field to the inductor's magnetic field. This interaction between the tank capacitor

Phase shift in the Hartley oscillator is accomplished in a similar way to that of the Colpitts oscillator. If you do not recall how the Colpitts functions, please refer to Module 22, Lesson 4. The main difference between the Hartley and the Colpitts is that the Hartley uses a tapped inductor to provide the 180° phase shift, whereas the Colpitts uses a capacitive voltage divider. In the Hartley type oscillator the tank circuit is excited by the voltage from the collector of the transistor. Look at the schematic and notice that the AC voltage at the bottom of the coil is 180° out-of-phase with the AC collector voltage of the transistor. Waveforms are shown on the schematic in order to help you understand the operation of the oscillator more readily. In this instance the inductance of the oscillator, specifically L_t, may be considered as an inductive voltage divider. Notice that the inductance in this example is center tapped. In actual practice the tap may be somewhat off center. The actual location of the tap depends on the amount of feedback which is required. Even though the tap may be somewhat off center, sufficient feedback can still be provided to maintain oscillation in the circuit.

Two simplified AC equivalent schematics are shown in Figure 2. These schematics are for the Hartley and the Armstrong oscillator.

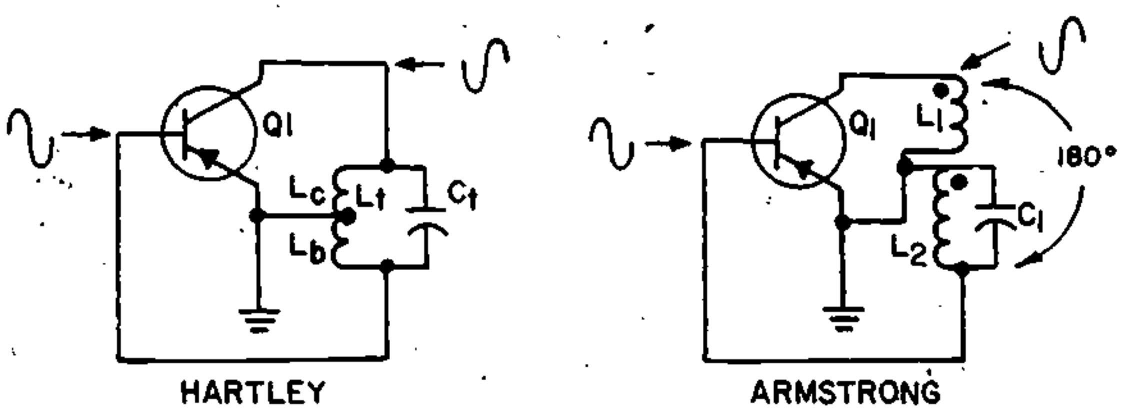


Figure 2

AC OSCILLATOR EQUIVALENTS

In the case of the Armstrong oscillator, feedback is accomplished by transformer action. Notice that the output signal from the collector of Q1 is transformer coupled from L1 to L2 and back to the base of the transistor. This in itself results in a 180° phase shift. The additional phase shift is accomplished by the action of the transistor. Phasing dots have been shown on the schematic to emphasize the phase shift that occurs in the transformer. If the connections of L1 and L2 are reversed, this prevents the circuit from

The modified circuit is shown in Figure 4.

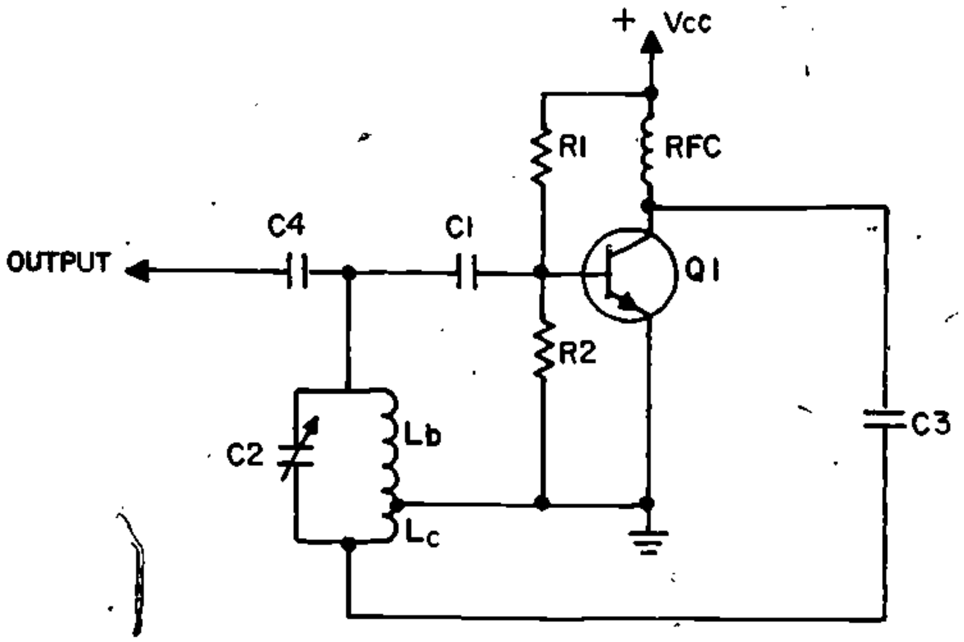


Figure 4

SHUNT TYPE HARTLEY OSCILLATOR

This is also the schematic of a shunt-fed Hartley oscillator. This type of oscillator has better frequency stability. To further improve the performance of the oscillator, an RFC is used instead of a resistor for the collector load. Because this device has little DC resistance and provides a large AC reactance it keeps the oscillating signal from entering the power supply source and increases the DC collector working voltage. You undoubtedly remember that AC entering the power supply source could cause interference with other circuits using the same power supply as a voltage source. Using the RFC as a collector load is not unique to the shunt-type Hartley oscillator. The RFC could also be used with a series fed oscillator circuit.

With series and shunt-fed Hartley oscillators, the transistors that are used may be either PNP, or NPN. These circuits may also be represented schematically in a different way.

and inductor is sometimes called the "flywheel effect".

The tank circuit has now been shocked into oscillation by the inductive action of L_c and L_b. Remember that once the tank begins to oscillate it will continue to oscillate as long as sufficient regenerative feedback is provided to overcome tank and circuit losses. In this case the tank signal is inverted by Q1 and coupled through to the bottom of L_c where the tank inverts the signal another 180°. This provides the positive regenerative feedback necessary to keep the tank circuit oscillating. Remember that the tank continues to oscillate as long as sufficient regenerative feedback is provided to compensate for tank and circuit power losses. You can see from this explanation that an oscillator is basically a tank circuit, an amplifier and a regenerative feedback path.

Refer again to the Hartley schematic shown in Figure 3. When the oscillator commences to oscillate, the base emitter voltage of Q1 drops to less than 0.6 volt. In some cases, this voltage may even be negative. The reason for this change in voltage is the charge on capacitor C1. In other words, the capacitor develops a voltage across it which opposes the transistor forward bias established by R1 and R2. As you know, this reduces the forward bias of Q1. Refer again to to the schematic shown in Figure 3 and notice that the current passes through coil L_c. Because the DC current flow through coil segment L_c increases the voltage drop across the coil, in some respects the coil acts like a series resistor. Remember that increasing the resistance of a tank coil reduces the Q of the coil and the tank circuit. There is one undesirable effect associated with this and that is that the tank bandwidth increases causing the oscillator to operate at a frequency other than that which was originally intended or desired.

Frequency stability of an oscillator circuit depends on the Q of the oscillator tank. With a high Q, good stability is provided, whereas a low Q tank produces less stability for the oscillator circuit. A method commonly used to improve the frequency stability of an oscillator circuit is to remove the DC current from the tank circuit. This is accomplished by moving the ground from the bottom of the tank to the emitter of Q1.

17

PROGRAMMED INSTRUCTION
LESSON 1

Hartley Oscillators

TEST FRAMES ARE 5, 10, 16, AND 20. PROCEED TO TEST FRAME 5 AND SEE IF YOU CAN ANSWER THE QUESTIONS. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

1. In Module 22 you learned about basic oscillators, including various types, and the frequencies at which they operate. You also learned about oscillator circuitry. The basic requirements for LC oscillator circuits are shown pictorially in Figure 1.

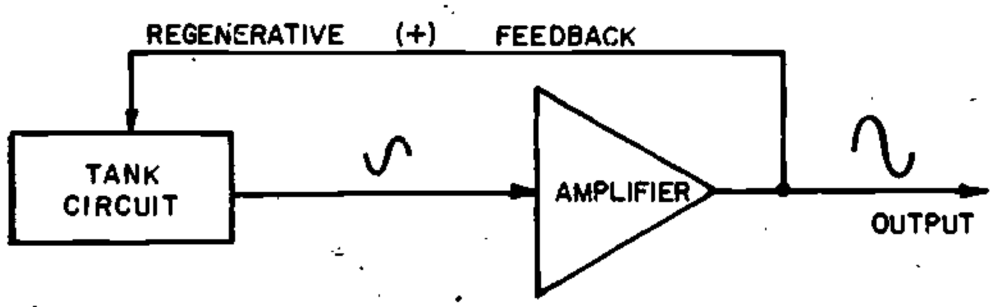
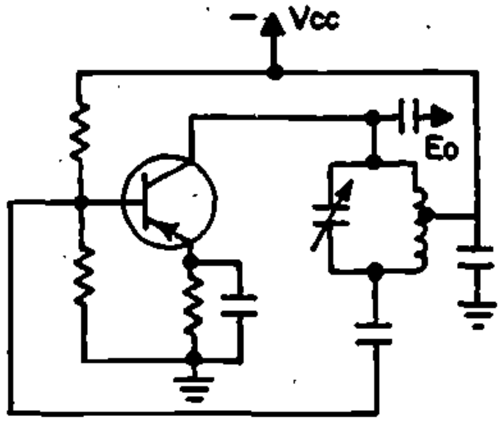


Figure 1

LC OSCILLATOR REQUIREMENTS

The ideas which are reflected pictorially in Figure 1 are basic to LC oscillator circuits. An LC oscillator has a tank circuit, an amplifier circuit, and provisions for regenerative feedback. The primary function of the tank circuit is to determine the oscillator frequency. The tank circuit may also provide the proper phase shift. This will be discussed in greater detail in subsequent frames. The purpose of the amplifier section is to provide the necessary gain and feedback voltage to sustain oscillations in the tank circuit.

Two additional examples of Hartley type oscillator schematics are shown in Figure 5.



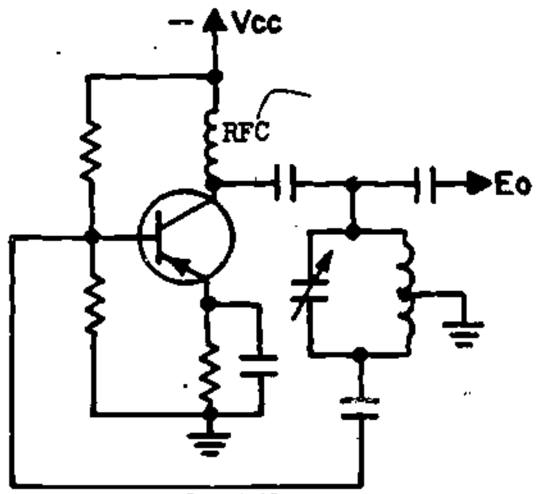


Figure 5

HARTLEY OSCILLATOR SCHEMATICS

As an exercise, trace the DC current paths from ground through the transistor to V_{cc} in order to verify the circuit names. One way of identifying the Hartley type oscillator circuit from other oscillator circuits is to determine whether the tank coil has been tapped. After you determine that the tank coil is tapped, you can easily determine whether the oscillator is series or shunt by tracing the current flow through the transistor. When the tank circuit is in parallel, or in shunt with the transistor, the circuit is a shunt- fed Hartley oscillator. When the transistor current passes through the tank coil, the circuit is a series- fed Hartley oscillator.

It is often necessary to determine the oscillating frequency of an oscillator. You may have used an oscilloscope to make this determination. Because the oscilloscope does not provide the accuracy required, a frequency counter is now the standard piece of test equipment used for determining frequency. The digital frequency counter is more accurate because it minimizes the loading of the oscillator circuit and provides a direct digital read-out of the oscillator frequency. The digital frequency counter is crystal controlled and is accurate to 1 part in 10^8 or 1 hertz in 100 MHz. One such frequency counter which you will have an opportunity to use in the job program is the AN/USM-207.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, PROCEED TO THE JOB PROGRAM. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH LEARNING CENTER INSTRUCTOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

from 1 Hz to thousands of megahertz. The actual amplitude and the specific output frequency depend on the equipment application. However, all oscillators strive for a constant amplitude and stable frequency output.

One of the functions of an oscillator is to

a. change AC to DC

b. change DC to AC

c. increase the AC input

d. rectify the AC input

---

b. change DC to AC

---

3. The amplifier section of an oscillator circuit is used to provide the necessary gain and feedback voltage to maintain tank oscillation. In order to sustain oscillations, the feedback must be of the proper phase. This means that the feedback voltage must be shifted 180° before it can be applied to the amplifier. Circuits which provide 180° phase shifts are common in LC oscillators. Some of the techniques which are used for obtaining this phase shift are depicted in Figure 3.

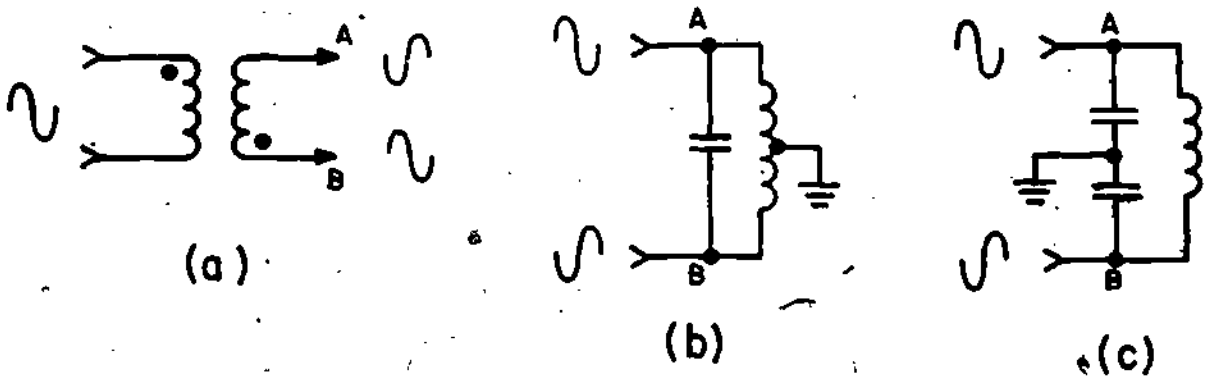


Figure 3

PHASE SHIFT TECHNIQUES

The three essential sections of LC oscillator circuits are ___1___, ___2___ and ___3___.

---

1. Tank Circuit
2. Amplifier
3. Regenerative feedback (in any order)

---

(2) Previously you learned that the function of a power supply is to convert AC to DC. The function of an oscillator is just the opposite. The oscillator circuit takes a DC voltage and converts it to an AC output. This is shown pictorially in Figure 2.

Figure 2

OSCILLATOR ICO

At this point you may wonder why it is necessary to convert DC to AC since we usually have AC available from the power source. Although AC voltage is available from the line, its frequency is usually 60Hz. Electronic equipments require different operating frequencies and thus many types of oscillator circuits are required. Oscillators provide output frequencies which range

d. All of the above

4. Oscillator circuits may be designed to operate with any of the amplifier classes you studied in Lesson 2 of Module 31. Each of the operating classes has certain advantages. For example, with Class A operation there is constant amplifier device conduction and a clean undistorted output waveform. However, from an efficiency standpoint, this type of amplifier is least efficient due to its internal power loss. Although the Class C amplifier conducts for less than 180°, this circuit provides the best power output. The disadvantage of the Class C amplifier is that the output waveform is not as faithful a reproduction of the input as in the Class A amplifier. Although Class A and Class C amplifiers are frequently used, the factor which determines which class to use in oscillator service depends on the oscillator power output requirement. Whenever a high power output is required, Class C operation is used. When the primary consideration is output waveform, Class A operation is used.

no response required

Notice that transformers may be used to provide a 180° phase shift in the oscillator circuit. As you examine Figure 3 notice that phasing dots are used to indicate points with identical phase in relation to time. Note specifically the schematic shown in Figure 3(a). With the input indicated, the sine wave associated with the primary of the transformer produces an identical phase signal at the dot, or B terminal, of the transformer secondary. This phase shift technique is commonly used in the Armstrong type oscillator which you studied in Module 22. The schematic shown in Figure 3(b), shows a tank circuit with a tapped inductance. This method is often used to provide out-of-phase voltages from a tuned tank. In this instance, Terminal A is 180° out-of-phase with respect to terminal B. This is one of the techniques that is often used with a Hartley type oscillator. The schematic in Figure 3(c), shows a tuned tank circuit which uses two capacitors in order to obtain out-of-phase voltages. In this case terminal A is 180° out-of-phase with respect to terminal B. The action is the same as indicated in the center schematic with the tapped inductance. The main difference is that a tapped inductance is not required. Recall that this technique was used with the Colpitts oscillator which you studied in Lesson 4 of Module 22.

Which method(s) are used to provide 180° of phase shift in oscillator circuits?

a. Transformers

b. A tuned tank with tapped inductance

c. A tuned tank with two series-connected capacitors

d. All of the above

---

1. a. change DC to AC
2. tank circuit, amplifier, and regenerative feedback (in any order)
3. a. regenerative
4. a. out-of-phase

IF YOUR ANSWERS MATCH THE CORRECT ANSWERS GO ON TO TEST FRAME 10. IF YOUR ANSWERS DO NOT MATCH GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 5 AGAIN.

6. A type of oscillator which is often used in electronic equipment is the Hartley oscillator. One common application of this type of oscillator is providing frequency injection for the mixer stage of a superheterodyne radio receiver. When the oscillator is used for this purpose it is sometimes called a local oscillator (LO). Other applications for the Hartley circuit include the variable frequency oscillator, or VFO stage, in radio transmitters and signal generators. The advantage of using a Hartley type oscillator is that it has good frequency stability over a wide range of frequencies and produces a constant amplitude sine wave output.

The main advantage of the Hartley type oscillator is it provides

a. a constant amplitude sine wave output with good frequency stability
b. an increased output voltage with average frequency stability
c. variable output with a minimum of input regulation
d. little frequency stability but provides a constant sine wave output

---

a. a constant amplitude sine wave output with good frequency stability

(5.) THIS IS A TEST FRAME. AFTER YOU ANSWER THE QUESTIONS COMPARE YOUR ANSWERS WITH THE ANSWERS GIVEN AT THE TOP OF THE PAGE FOLLOWING THE QUESTIONS.

1. Oscillators function to

   a. change DC to AC

   b. change AC to DC

   c. increase AC output voltage

   d. shift the phase of the input voltage

2. The three sections of an oscillator circuit are

   1.

   2.

   3.

3. In order to keep an oscillator circuit operating the feedback must be

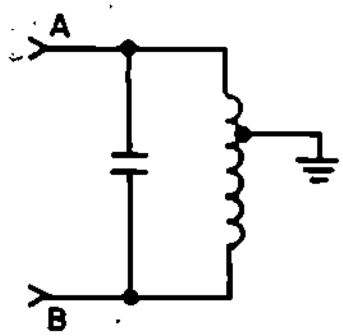
   a. regenerative

   b. degenerative

   c. out-of-phase

   d. zero

4. The phase of the signal at terminal A in the figure below is ________________ ________ with the signal at terminal B.



   a. out-of-phase

   b. in phase

25

center of the tank, the AC voltage at each end of the tank is 180° out-of-phase in respect to the common ground connection. Since the input to the amplifier is felt directly across capacitor C2, this voltage is 180° out-of-phase with the voltage at the collector end of the tank circuit. Therefore, the total phase shift around the loop is 360° and this causes the circuit to continue to oscillate. Remember the oscillator output frequency is determined in this case by the inductor L1 and the series equivalent of capacitor C1 and C2.

The AC voltage across C2 is __________ with the AC voltage across ______.

a. in phase, C1

b. out-of-phase, C1

c. in phase, C-E of Q1

d. out-of-phase, B-E of Q1

---

b. out-of-phase, C1

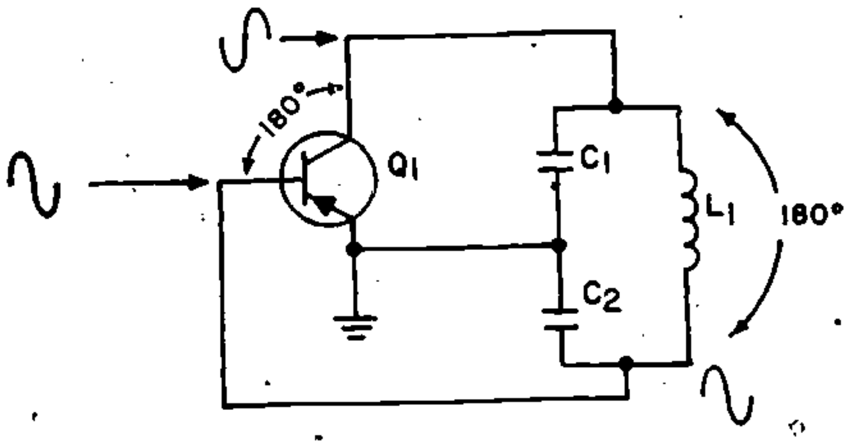


Figure 4

COLPITTS OSCILLATOR AC-EQUIVALENT

(7.) To help you understand the operation of the Hartley oscillator, a quick review of the Colpitts oscillator is presented here. Recall that you studied this circuit in Lesson 4 of Module 22. The equivalent AC circuit is shown in Figure 4. Remember equivalent circuits omit bias voltages and some components for ease in understanding the main point.

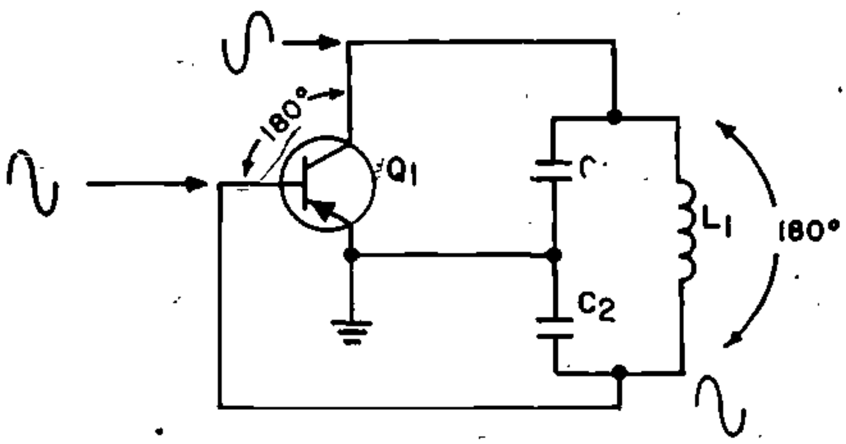
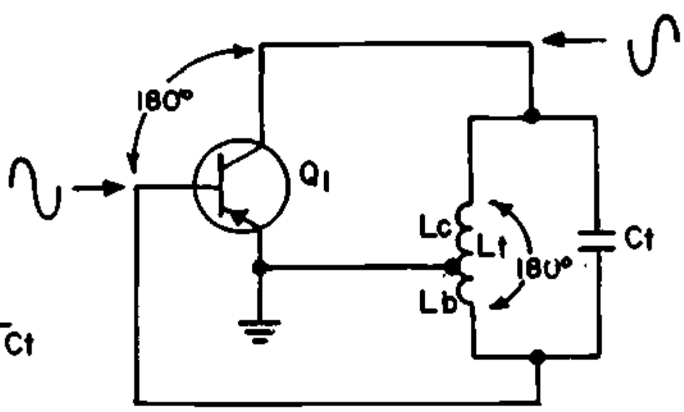


Figure 4

COLPITTS OSCILLATOR AC-EQUIVALENT

Notice that voltage phase shifts are indicated at key points. Recall that one of the key requirements for any oscillator is that the regenerative feedback voltage of the oscillator must be in phase with the signal on the base of Q1. The amplifier shown in the Figure is for a familiar common emitter type oscillator circuit. This type of circuit configuration produces 180° of phase shift between the base and the collector signals. An additional 180° of phase shift is accomplished by the tank circuit which is comprised of L1, C1, and C2. The output signal from the collector of Q1 excites the LC resonant tank and produces tank oscillations. Because AC ground is at the

(9.) Recall that the function of an oscillator is to produce a constant amplitude, stable output signal. Remember that unless feedback is regenerative, damping of the tank oscillations will occur. If the feedback is exactly in-phase, little feedback is needed to overcome circuit losses and sustain oscillation. A difference of a few degrees either way will still allow the circuit to continue to oscillate. Of course, the amplitude of the feedback necessary to sustain oscillation is much less when the feedback is in phase. The schematic shown in Figure 5 is the AC equivalent of a Hartley oscillator.



$$f_0 = \frac{1}{2\pi\sqrt{L_t C_t}}$$

Figure 5

HARTLEY OSCILLATOR-EQUIVALENT AC CIRCUIT

8. Again refer to the schematic in Figure 4 paying particular attention to the tank circuit comprised of C1, C2, and L1. Decreasing the capacitance of C2 will increase its reactance and this results in a greater voltage across the capacitor. C2's voltage provides the regenerative feedback required to sustain tank oscillations.

Optimum regenerative feedback depends on the relationship, or ratio, of the capacitance of C1 and C2. This factor in conjunction with the biasing components also determines the oscillator class of operation.

The oscillator may be tuned by varying the inductance of coil L1. Thus, the LC tank circuit performs two functions in the Colpitts oscillator. First, it determines the oscillator output frequency and second, it provides the necessary 180° of phase shift. If you do not recall how the Colpitts oscillator operates, please refer to Module 22, Lesson 4.

The tank circuit in the Colpitts oscillator performs the function(s) of

a. providing 360° phase shift and rectifying output

b. determining oscillator output frequency and providing 180° phase shift

c. providing degenerative feedback

d. none of the above

---

b. determining oscillator output frequency and providing 180° phase shift

29

(10) THIS IS A TEST FRAME, AFTER YOU ANSWER THE QUESTIONS, COMPARE YOUR ANSWERS WITH THE ANSWERS GIVEN AT THE TOP OF THE PAGE FOLLOWING THE QUESTIONS.

1. A Hartley type oscillator provides
   a. constant output with a minimum of input regulation
   b. an increased output voltage with average frequency stability
   c. a constant amplitude sine wave output with good frequency stability
   d. very little frequency stability but a constant sine wave output

2. In order for an oscillator to continue oscillating the feedback voltage must be
   a. 90° out-of-phase with the oscillator output
   b. 90° out-of-phase with the oscillator input
   c. in phase with the tank voltage
   d. out-of-phase with the tank voltage

3. The tank circuit in the Hartley oscillator operates to
   a. maintain a damped output voltage
   b. provide a 180° phase shift and constant oscillator output frequency
   c. provide a 360° phase shift and rectify the output
   d. provide a 90° phase shift to maintain a constant oscillator output frequency

---

This oscillator accomplishes the phase shift action in a similar way to the Colpitts. As you compare the circuit for the Colpitts and the Hartley you can see that the only real difference between the two is that the Hartley oscillator utilizes a tapped inductor to provide the 180° phase shift instead of a capacitive voltage divider as used in the Colpitts. In the Hartley, the tank circuit is excited by the voltage from the collector of the transistor. Notice that the voltage at the bottom of the coil is 180° out-of-phase with the collector of the transistor. To help you understand the operation of the Hartley, waveforms are shown on the schematic. In the case of the Hartley, the inductance, specifically L_t, may be considered an inductive voltage divider. Because the amount of feedback provided when the coil is center tapped is more than required to maintain oscillation in the circuit, the actual tap may be somewhat off-center. If the tap is moved toward the base end of coil L_t, the amount of feedback is reduced. In this manner optimum feedback amplitude can be provided to maintain circuit oscillation.

The amount of feedback provided by the Hartley oscillator shown in Figure 5 depends on the

a. tap position on inductor L_t

b. value of capacitor C_t

c. both of the above

---

a. tap position on inductor L_t

31

1. c. a constant amplitude sine wave output with good frequency stability.
2. c. in phase with the tank voltage
3. b. provide a 180° phase shift and constant oscillator output frequency

IF YOUR ANSWERS MATCH THE CORRECT ANSWERS, GO ON TO TEST FRAME 16. IF YOUR ANSWERS DO NOT MATCH THE ANSWERS GIVEN, GO BACK TO FRAME 6, AND TAKE THE PROGRAMMED SEQUENCE AGAIN, BEFORE TAKING TEST FRAME 10 AGAIN.

(11) The simplified AC equivalent schematics shown in Figure 6 are for a Hartley and an Armstrong oscillator.

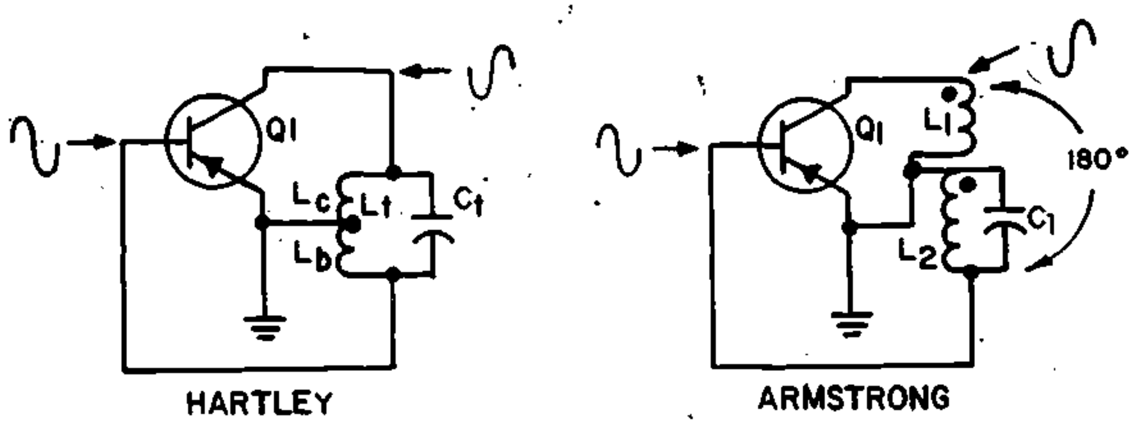


Figure 6

AC EQUIVALENTS

Notice that in the Armstrong oscillator feedback is accomplished by transformer action. The output signal from the collector of Q1 is transformer coupled from L1 to L2 and back to the base of the transistor. In this case the transistor produces the necessary 180° phase shift and this, combined with the transformer 180° shift, produces a total shift of 360°. Phasing dots have been shown on the Armstrong schematic to show equivalent circuitry. Reversing the connections on L1 and L2 will prevent the circuit from oscillating. Now look at the Hartley oscillator shown in Figure 6. In this case, the primary

(13) Recall that one of the characteristics of all oscillators is that they have a working amplifier circuit and that the amplifier must be forward biased in order to provide amplification. The schematic shown in Figure 7 is that of a series-fed Hartley oscillator circuit.

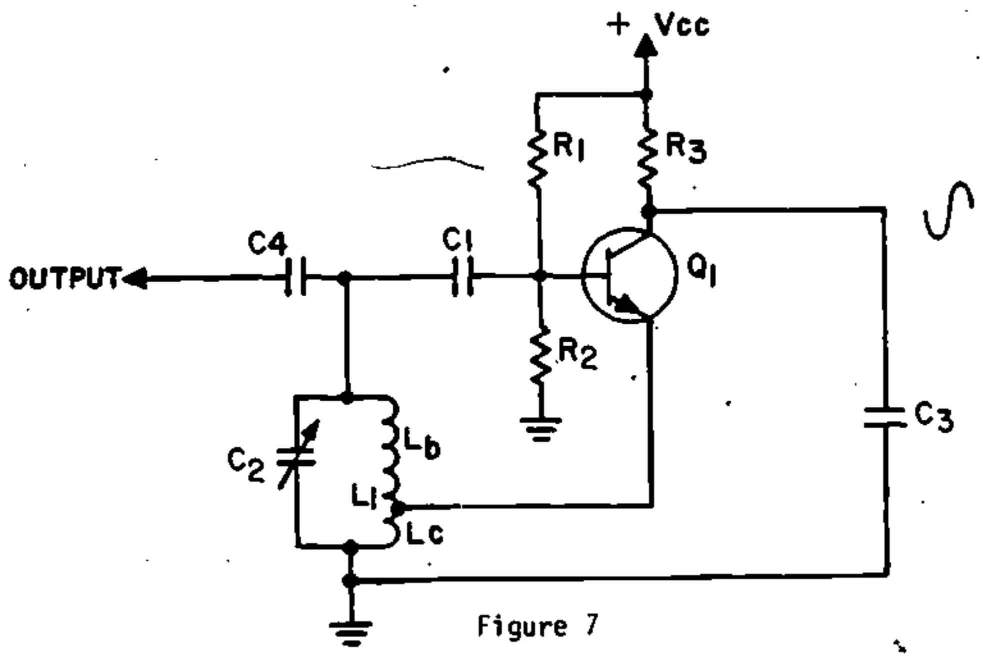


Figure 7

SERIES-FED HARTLEY OSCILLATOR

When you examine the schematic you can readily see that R1 and R2 provide the forward bias for Q1. Current which flows from ground to Vcc places the forward bias of Q1 at approximately 0.6 volts positive. This forward bias is necessary in order to cause the transistor to conduct and oscillation to begin. The transistor current then flows from ground through tank coil L_C, Q1, R3, and thence to Vcc. This creates a magnetic field around coil L_C as shown in Figure 8.

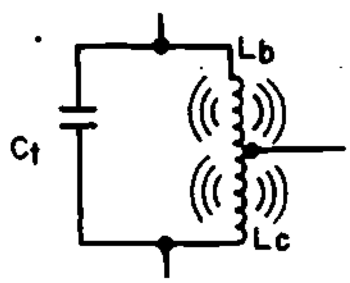


Figure 8

INDUCTIVE ACTION Lc-Lb

of the transformer is designated as L_c and the secondary section is designated as L_b. Even though these coils have a common point, mutual coupling still exists between them. Current flowing through L_c induces a voltage across L_b and produces a transformer coupling action just as with the Armstrong circuit. This type of action is often referred to as "auto transformer action".

The feedback in both the Armstrong and Hartley oscillator circuits is accomplished through

a. transformer coupling action

b. the internal action of Q1

c. the tank capacitor

d. none of the above

---

a. transformer coupling action

---

(12) Up to this point the basic purpose of the instruction was to acquaint you with the basic principles which apply to all types of oscillator circuits. The remainder of this lesson will be concerned with the two basic types of Hartley oscillators. The two major classifications for Hartley oscillators are: series and shunt-fed oscillators.

The two types of Hartley oscillators are__________ and__________

---

series and shunt or shunt and series

(14.) Refer again to the schematic shown in Figure 7. The tank has been shocked into oscillation by the induction action of L_c and L_b. Once the tank begins to oscillate the voltage at the top of the tank swings in a negative direction. This reduces the forward bias on Q1 and the magnetic field around the inductance L1. The exchange of energy between the tank coil and capacitor produces a sine wave voltage across the tank. This provides a positive regenerative feedback signal to the base of the transistor which is in phase with the tank signal. As a result of this, the tank oscillations are reinforced. As you recall, once oscillation begins, it continues as long as sufficient regenerative feedback is provided to compensate for losses in the oscillator.

One function of the tap on L1 in the Hartley oscillator is to

a. control oscillation frequency

b. provide in phase feedback voltage to the tank

c. couple the feedback into the power supply

d. none of the above

---

b. provide in phase feedback voltage to the tank

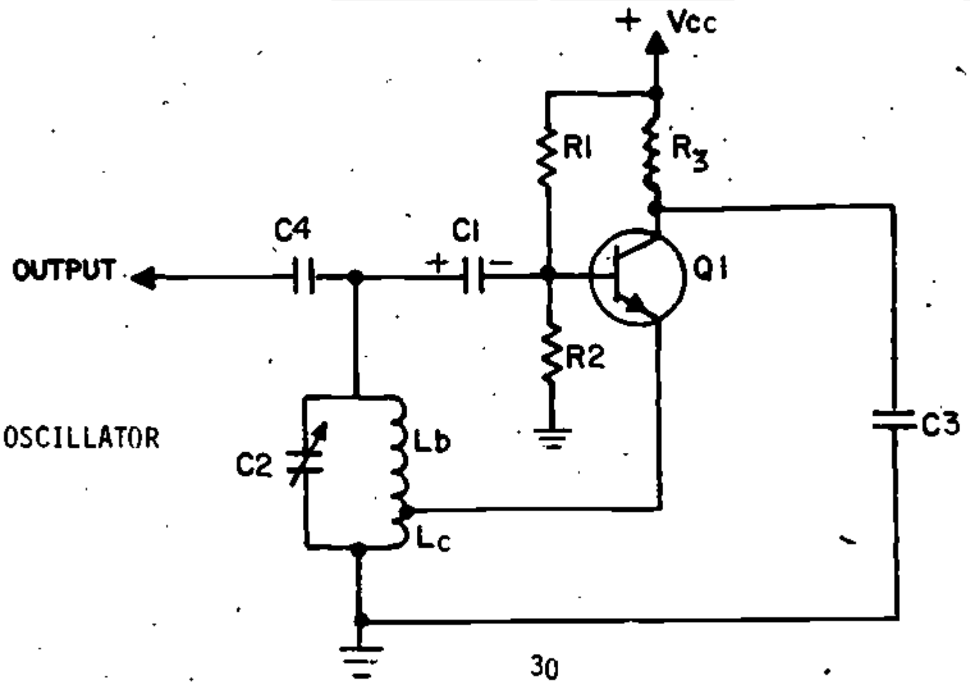


Figure 7

SERIES-FED HARTLEY OSCILLATOR

The magnetic field around coil L_c induces a voltage into coil L_b. See Figure 8. This increases the forward bias of the transistor and increases its conduction.

Simultaneous with this action, the induced voltage in L_b and L_c starts oscillation inside the tank circuit. The charge and discharge of C2 causes an exchange of energy from the capacitor electric field to the inductor magnetic field. This interaction between the inductance and capacitor is sometimes called the "flywheel effect."

Interaction between an inductance and capacitor in a tuned circuit is sometimes called the ____________ ____________.

---

flywheel effect

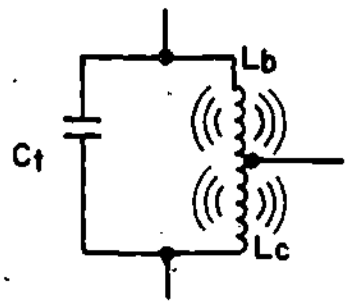


Figure 8

INDUCTIVE ACTION L_c-L_b

Recall that the higher the Q of the oscillator tank, the greater the frequency stability of the oscillator.

A high tank Q value in the oscillator circuit results in

a. less frequency stability

b. the same amount of frequency stability

c. greater frequency stability

d. has no effect on frequency stability

---

c. greater frequency stability

(15) Again refer to the Hartley schematic shown in Figure 9. Once the oscillator begins to oscillate, the base-emitter voltage of Q1, as measured with a voltmeter, drops to less than 0.6 volt. In fact it may even become negative. The reason for this is the charge on C1. C1 couples the tank signal to the transistor base and isolates the tank from the direct current, or DC biasing network. Thus, the capacitor develops a small voltage across it which opposes the transistor forward bias established by R1 and R2. This reduces the positive base-emitter potential of Q1. The amplitude of the tank signal must be sufficient to ensure continued transistor conduction. The conduction time of Q1 determines the class of oscillator operation.

Again refer to the schematic in Figure 9. Trace the current flow from ground through Q1. Notice that the current passes through coil L_C. This current flow increases the voltage drop across the coil and the coil functions like a series resistor. You should recall that increasing the resistance of a tank coil reduces the Q of the coil and the tank circuit. There is one undesirable effect associated with this and that is the tank bandwidth increases, causing the oscillator to oscillate at a frequency other than the frequency originally desired.

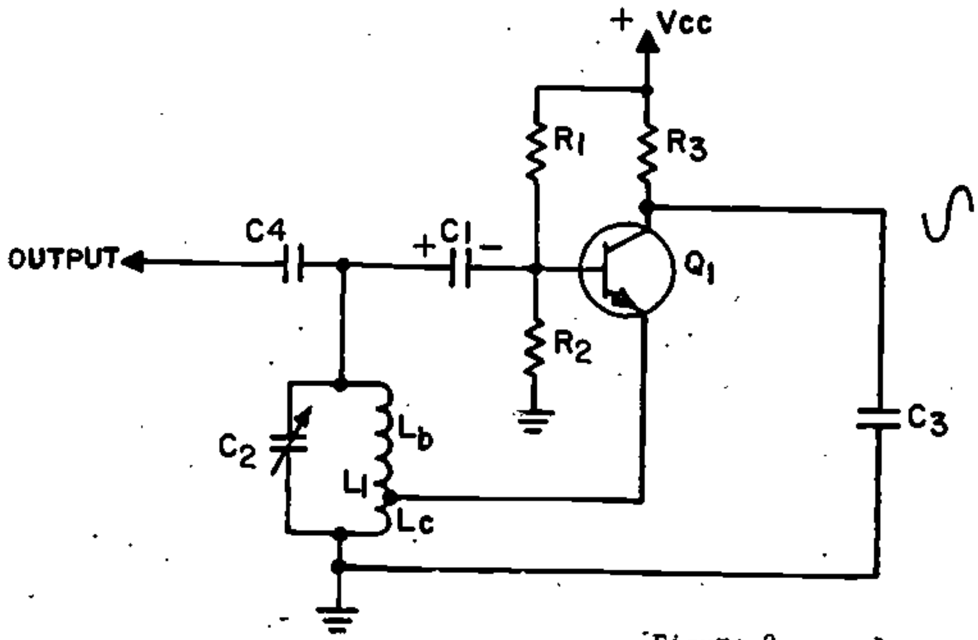


Figure 9

SERIES-FED HARTLEY OSCILLATOR

1. a. sufficient to overcome internal signal losses of the ciruit and supply required output power
2. a. XL/R
3. a. increasing the Q of the oscillator tank

IF YOUR ANSWERS MATCH THE CORRECT ANSWERS, GO ON TO TEST FRAME 20. IF YOUR ANSWERS DO NOT MATCH, GO BACK TO FRAME 11 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 16 AGAIN.

17. The frequency stability of an oscillator circuit depends on the Q of the oscillator tank. A high Q tank results in good stability whereas a low Q tank produces less stability for the oscillator circuit. One method used to increase the frequency stability is to remove the DC amplifier current from the tank circuit. By moving the ground from the bottom of the tank to the emitter of Q1, the DC path is removed from the tank. A shunt-fed Hartley oscillator schematic is shown in Figure 10.

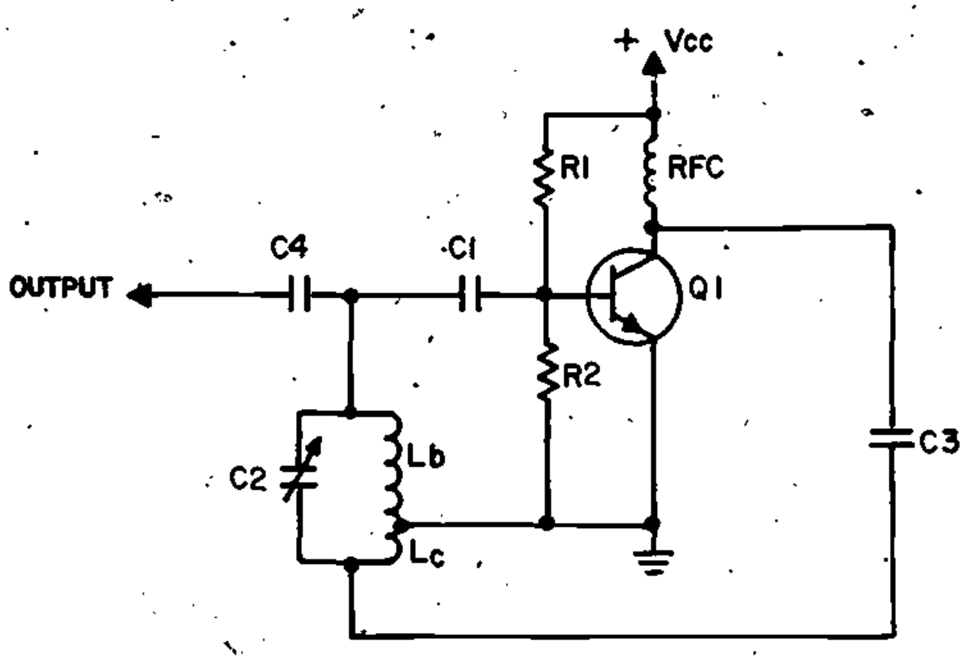


Figure 10

SHUNT-FED HARTLEY OSCILLATOR

(16) THIS IS A TEST FRAME, AFTER YOU ANSWER THE QUESTIONS, COMPARE YOUR ANSWERS WITH THE ANSWERS GIVEN AT THE TOP OF THE PAGF FOLLOWING THE QUESTIONS.

1. The amount of feedback necessary to keep an oscillator circuit oscillating must be

   a. sufficient to overcome internal signal losses of the circuit and supply required output power.

   b. less than the signal losses of the circuit.

   c. greater than the signal losses of the circuit but less than the output power.

2. The Q of a coil in a tank circuit depends on the ratio of

   a. XL/R

   b. R/XL

   c. R/XC

3. The frequency stability of an oscillator tank may be increased by

   a. increasing the Q of the oscillator tank.

   b. decreasing the Q of the oscillator tank.

   c. varying the Q of the oscillator tank.

   d. none of the above.

---

those already shown in this lesson. Two additional examples of Hartley oscillator schematics are shown in Figure 11.

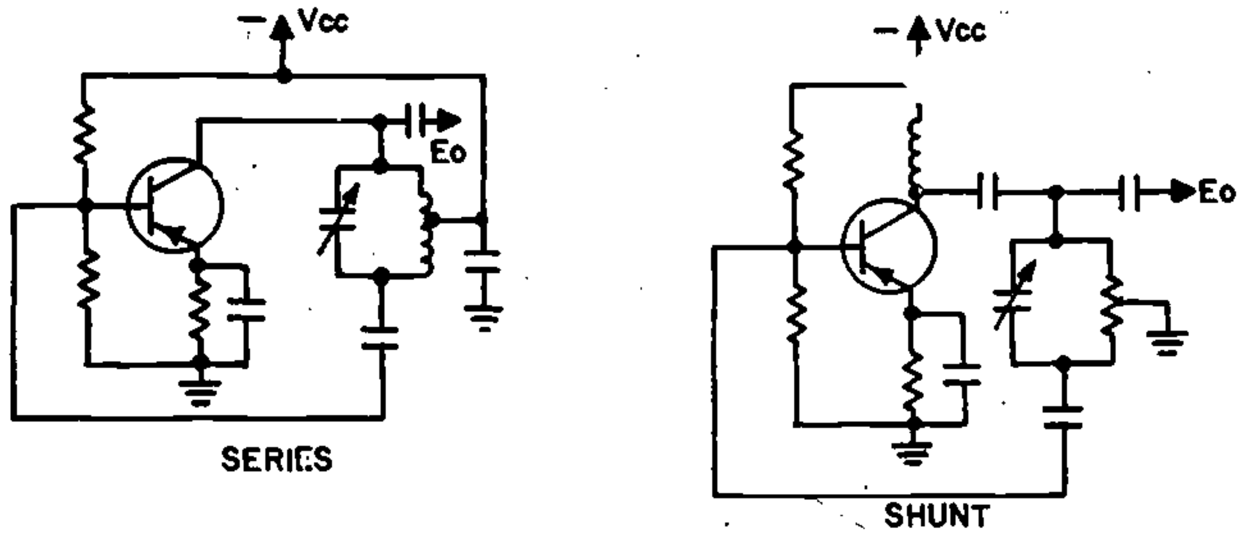


Figure 11

SEPIES/SHUNT HARTLEY OSCILLATORS

The characteristic which distinguishes the Hartley type oscillator circuit from other oscillator circuits is the tank coil tap. Once you determine that the tank coil is tapped, you can easily determine whether the oscillator is series or shunt by tracing the current flow through the transistor. When the transistor current passes through the tank coil, the circuit is a series-fed Hartley oscillator. In cases where the tank circuit is in parallel or in shunt with the transistor, the circuit is a shunt-fed Hartley oscillator.

---

no response required

Now, the higher Q of the tank circuit improves the frequency stability of the circuit. When you compare the schematics for the series and shunt-type Hartley oscillators, notice that instead of using a resistor for the collector load, the shunt circuit uses a radio frequency choke (RFC). Since this device has little DC resistance and provides a large AC impedance, it keeps the oscillating signal from entering the power supply source (Vcc) and raises the DC collector working voltage. As you know, AC entering the power source could cause interference with other circuits using the same voltage source. The technique of using the RFC as a collector load could also be employed with the series-fed Hartley oscillator.

An advantage of using a radio frequency choke in the shunt type oscillator is that the choke

a. has the advantage of little current drain

b. provides a large DC resistance and a small AC impedance

c. is more stable due to an increased resistance

d. provides a large AC impedance and little DC resistance

---

d. provides a large AC impedance and little DC resistance

---

(18) One additional point concerning series and shunt-type Hartley oscillators. The type of transistors used in the circuits can be either PNP or NPN. Further, there are other ways to represent the circuits schematically th.


THEY ALL NEED
OSCILLATORS

19 Often it is necessary to determine the operating frequency of an oscillator. The basic method used for making this determination is shown pictorially in Figure 12.

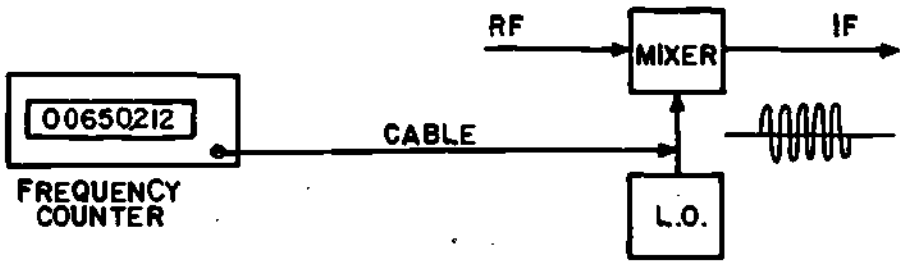


Figure 12

MEASURING OSCILLATOR FREQUENCY

The diagram shows a digital frequency counter measuring the local oscillator (L.O.) frequency of a superheterodyne receiver. Previous methods for determining oscillator frequency do not provide the accuracy required. Therefore the frequency counter is now the standard piece of test equipment for frequency measurement. A digital frequency counter is more accurate because it minimizes loading of the oscillator and provides a direct read-out of the frequency. Accuracy of the counter depends on the crystal controlled oscillator which is part of the counter. The accuracy of this type of test equipment approximates one part in 10^8 or 1 hertz in 100 MHz. You will have an opportunity to use a frequency counter as part of the job program associated with this lessor. The frequency counter which you will use is the AN/USM-207.

---

no response required

---

1. c. radio frequency choke

2. a. tank coil tap

3. c. no forward bias

IF YOUR ANSWERS MATCH THE CORRECT ANSWERS YOU HAVE COMPLETED THE PROGRAMMED INSTRUCTION FOR LESSON 1, MODULE THIRTY TWO. OTHERWISE GO BACK TO FRAME 17 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 20 AGAIN.

AT THIS POINT YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, PROCEED TO THE JOB PROGRAM. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH LEARNING CENTER INSTRUCTOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

(20) THIS IS A TEST FRAME. AFTER YOU COMPLETE THE QUESTIONS COMPARE YOUR ANSWERS WITH THE ANSWERS GIVEN AT THE TOP OF THE PAGE FOLLOWING THE QUESTIONS.

1. In a shunt-type Hartley oscillator a __________ may be used for the transistor collector load.

    a. variable resistance

    b. variable capacitance

    c. radio frequency choke

2. A distinguishing characteristic of Hartley type oscillators is the

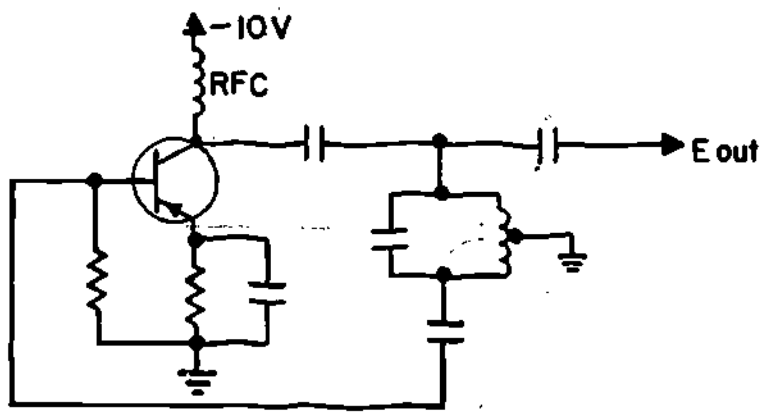
    a. tank coil tap.

    b. variable frequency of the oscillator.

    c. use of PNP transistors.

    d. use of NPN transistors.

3. Study the circuit below and determine why it does not function.



    a. Incorrect collector voltage

    b. Improper tank tap

    c. No forward bias

    d. It should work

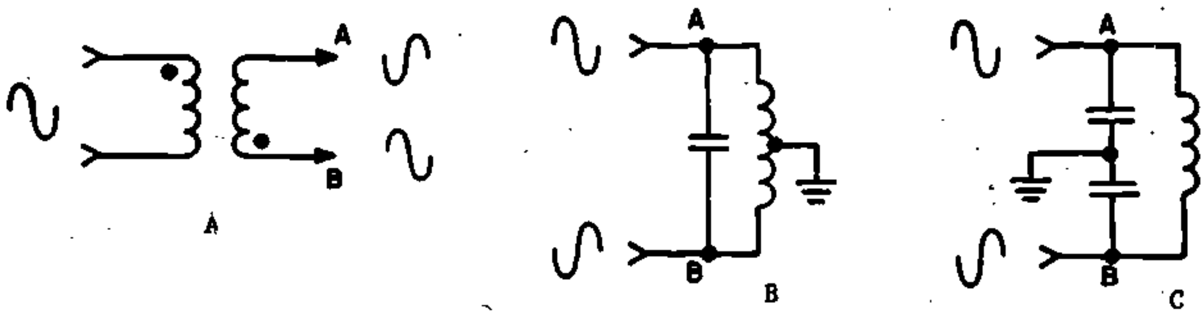


Figure 2

PHASE SHIFT TECHNIQUE

To help you understand the phase shift, phasing dots are shown to indicate points at which the phase is identical. Notice that transformers are used to provide a 180° phase shift. The transformer schematic shown in 2A illustrates that a sine wave input to the primary of the transformer will produce an identical phase signal at terminal B of the transformers secondary. This method of accomplishing phase shift through transformer action is commonly used with the Armstrong type oscillator which you studied in Module 22. The schematic in Figure 2B shows a tank circuit with a tapped inductance winding. This tank circuit provides out-of-phase voltages across the inductance. In other words terminal A is 180° out-of-phase with terminal B. This is a technique which is often used with a Hartley type oscillator. Use of this technique with the Hartley oscillator will be discussed in detail in subsequent paragraphs of this lesson. The schematic shown as Figure 2C shows a tuned tank circuit which uses capacitors in order to obtain the out-of-phase voltage. In this case terminal A is 180° out-of-phase with respect to terminal B. Examination of this schematic shows that the output is identical to the output indicated on schematic 2B which uses a tapped transformer. You probably remember that this technique is used with the Colpitts oscillator which you studied in Lesson 4 of Module 22.

Oscillator circuits may be designed to operate with any of the amplifier classifications you studied in Module 31. Each of the operating classes has certain distinct advantages. For example, a Class A amplifier provides constant conduction with a clean undistorted output waveform even though it is not the most efficient type of amplifier. The reason it is not efficient is that there is a fairly large internal power loss. A Class C amplifier provides the best power output even though it conducts for less than 180°. The main disadvantage of the Class C amplifier is that the output waveform is not a faithful reproduction of the input waveform. Class A and Class C amplifiers are used most frequently in oscillators. The factor which determines which classification of amplifier to use depends on the oscillator power output requirement. The Class C amplifier is used where a high power output is required and Class A is used when the main consideration is stability of the output waveform.

NARRATIVE
LESSON 1

Hartley Oscillators

In Module 22 you learned about the various types of oscillators and the frequencies at which they operate. You also learned that there are three basic requirements for all LC oscillator circuits. These requirements are shown pictorially in Figure 1.

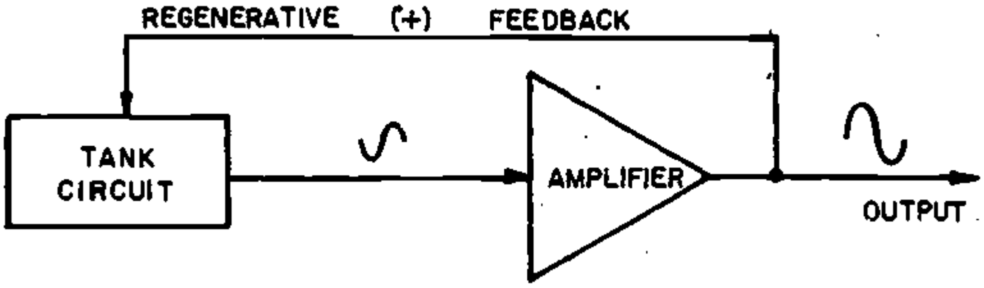


Figure 1

LC OSCILLATOR BLOCK DIAGRAM

Every LC oscillator has a tank circuit, amplifier circuit, and provision for regenerative feedback. The purpose of the tank circuit is to determine the oscillator frequency and in many circuits it also provides the required phase shift to the feedback voltage.

In your previous study of power supplies you learned that in most instances power supplies were used to convert AC to DC. One function of an LC oscillator is just the opposite. An oscillator converts a DC input into a stable, constant amplitude AC output. You may wonder why it is necessary to convert DC to AC since AC is usually available from the power source. Although AC voltage is available, the only frequency available is usually 60 hertz. Since different types of electronic equipments require different operating frequencies, oscillators which are capable of developing these frequencies are needed. Oscillators may be designed to provide output frequencies which range from 1 hertz to thousands of megahertz. The actual frequency depends on the specific equipment application. To assure the continued oscillation of the tank circuit, feedback of the proper phase must be provided. Further, the amplifier section must provide the necessary gain in voltage to maintain oscillation. Since the feedback voltage must reinforce tank oscillations, circuits which provide 180° phase shifts are common in LC oscillators. Some of the techniques which are used to accomplish the phase shift are shown in Figure 2.

Again refer to the schematic shown in Figure 3, paying particular attention to the tank circuit comprised of C1, C2, and L1. Decreasing the capacitance of C2 results in an increase in its reactance and a greater voltage across the capacitor. The voltage across this capacitor provides the necessary regenerative feedback to sustain tank oscillation. The oscillator frequency is usually changed by varying the inductance of coil L1. In this example the LC tank circuit of the Colpitts oscillator performs two functions. Besides determining the oscillator output frequency it also provides a 180° phase shift.

If you do not remember how the Colpitts oscillator functions please refer to Lesson 4 of Module 22.

Recall that the purpose of an oscillator circuit is to produce a constant amplitude and stable frequency output signal. Unless the oscillator output is of sufficient magnitude to replenish internal power losses, the oscillator will stop oscillating. When the tank feedback is exactly in phase with the oscillator, less feedback is required to overcome internal power losses. Even though the oscillator circuit will continue to oscillate when there is a slight difference of a few degrees in the feedback to the tank, this is not the most efficient application of regenerative feedback. Oscillation is easier to sustain when the feedback to the tank is exactly in phase with the tank oscillations. The schematic shown in Figure 4 is the AC equivalent of a Hartley type oscillator.

$$f_0 = \frac{1}{2\pi\sqrt{L_t C_t}}$$

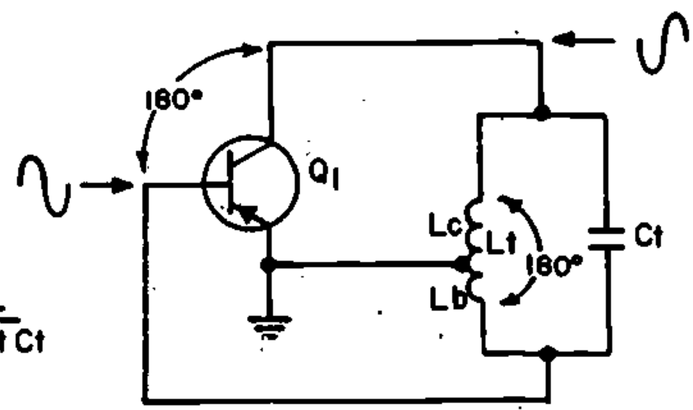


Figure 4

EQUIVALENT AC CIRCUIT HARTLEY OSCILLATOR

A type of oscillator that is used quite frequently in electronic equipment is the Hartley oscillator. The Hartley oscillator is often used to provide frequency injection for the mixer stage of superheterodyne radio receivers. When the oscillator is used for this purpose it is usually called a local oscillator (LO). The Hartley circuit is also used as a variable frequency oscillator (VFO) stage in radio transmitters and signal generators. The Hartley oscillator has the advantage of good frequency stability over a wide range of frequencies and the production of a constant amplitude output sine wave. There are two major classifications of Hartley oscillators. These oscillators are classified as series or shunt depending on the actual circuit configuration.

To help you understand the operation of the Hartley oscillator, a brief review of how the Colpitts oscillator functions is included. Remember you studied the Colpitts oscillator in Lesson 4 of Module 22. The schematic shown in Figure 3 is the AC equivalent of a Colpitts oscillator.

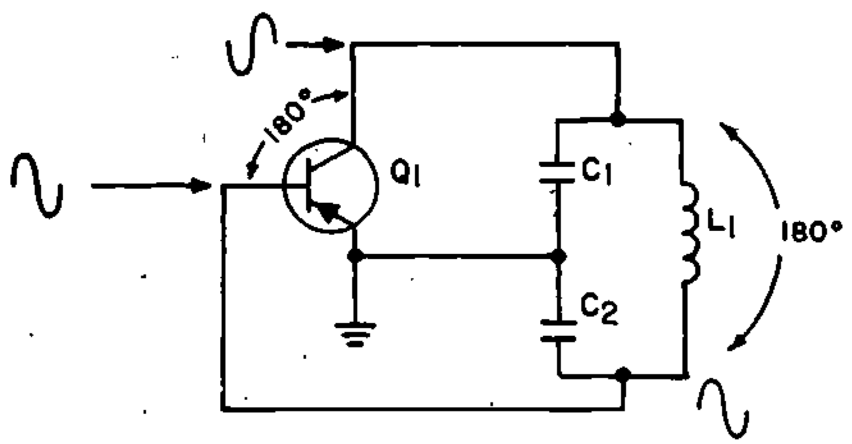


Figure 3

AC EQUIVALENT-COLPITTS OSCILLATOR

Voltage phase shifts are shown with arrows at key points to help you understand the operation of this type of oscillator. The schematic shown in the figure is for the familiar common emitter type oscillator circuit. This type of circuit produces a 180° phase shift between the base and collector of the transistor. An additional 180° of phase shift is provided by the tank circuit comprised of L1, C1, and C2. The total phase shift of this circuit is 360° which provides the necessary regenerative feedback to compensate for internal power losses and sustain oscillation in the tank circuit.

The remainder of this lesson explains the operation of series and shunt-fed Hartley oscillators. The schematic shown in Figure 6 is for a series-fed Hartley oscillator circuit.

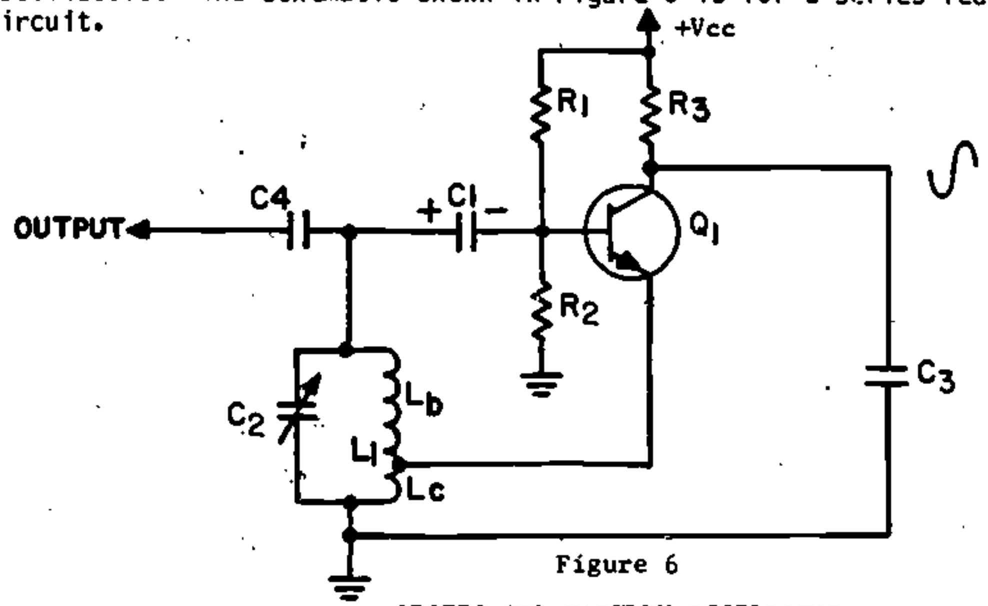


Figure 6

SERIES-FED HARTLEY OSCILLATOR

Notice that R1 and R2 provide the forward bias for Q1. In this case current flowing from ground through R2 to V_{CC} forward biases Q1 at approximately 0.6 volts positive. This forward bias is necessary in order for oscillation to begin. In this case current flows from ground through tank coil L_c, Q1, R3, and finally to V_{CC}. The current flow creates a magnetic field around coil L_c and induces a voltage into coil L_b. As a result of this, the forward bias of Q1 increases and the transistor conducts more. The transistor's conduction will follow the voltage across the tank. At the same time, the induced voltage across L_b and L_c starts oscillations within the tank circuit. The charging and discharging of C2 causes an exchange of energy from the capacitor electric field to the inductor magnetic field. The interaction between the inductance and capacitor is sometimes referred to as the "flywheel effect."

Refer again to the schematic shown in Figure 6. Due to the inductive action of L_c and L_b, the tank circuit has been shocked into oscillation. When oscillation begins, the voltage at the top of the tank swings in a negative direction. This reduces the forward bias of Q1 and changes the magnetic field around L1. The exchange of energy between the tank coil and the capacitor produces a sine wave voltage across the coil. Q1 amplifies and inverts the tank sine wave voltage in order to produce a feedback signal which is applied to the collector of the transistor. The feedback is coupled from the collector of the transistor through capacitor C3 back to the tank circuit. Remember, the tank circuit alters the waveform 180° and the resulting feedback is in phase with the tank signal.

Phase shifting in this oscillator is accomplished in a way similar to that of a Colpitts oscillator. If you compare the schematic for the Colpitts and the Hartley you can see that the major difference between the two is that the Hartley uses a tapped inductor to provide a 180° phase shift whereas the Colpitts uses a capacitive voltage divider.

Waveforms are shown on the schematic to help you understand the operation of the Hartley oscillator. With this type oscillator, the inductance, specifically LT, may be considered as an inductive voltage divider. Although the schematic shows the inductance as being center tapped, this is not always the case. The tap location on the inductance may be somewhat off center. The location of the tap effects the amount of feedback. More feedback is obtained as the tap is moved toward the collector side of the tank. The main consideration in tap location is that optimum feedback be provided to allow for suitable power output and to compensate for internal power losses of the oscillator. Too much feedback will overdrive the tank and cause possible instability and waveform distortion; too little feedback will cause the oscillator to stall or stop oscillation.

The schematics shown in Figure 5 are simplified AC equivalents for Hartley and Armstrong oscillators.

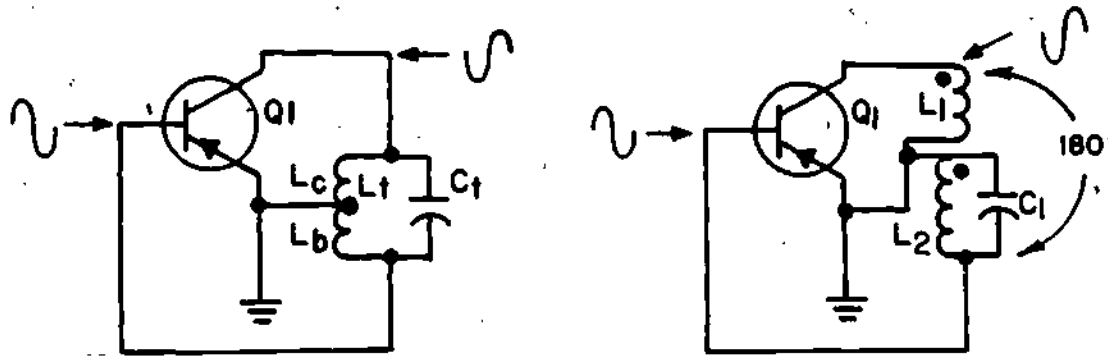


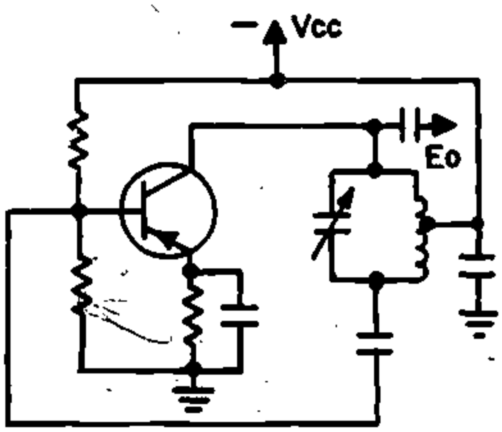
Figure 5

AC CIRCUIT EQUIVALENTS

As you study the Armstrong circuit you can readily see that the oscillator feedback is the result of transformer action. In this example the output signal of the collector of Q1 is transformer coupled from L1 to L2 and back to the base of Q1. The transistor produces a 180° phase shift and this shift combined with the transformer shift results in a total phase shift of 360°. With the Hartley schematic, the transformer primary is L_c. The secondary is designated as L_b. Though the coils have a common point, mutual coupling still exists between the coils. Current flowing through L_c induces a voltage in L_b, producing transformer coupling comparable to that of the Armstrong circuit.

Since the shunt Hartley circuit increases the Q of the tank, it also improves the frequency stability of the oscillator. As you compare these schematics for the series and shunt-fed Hartley oscillators, notice that in lieu of using a resistor for the collector load in the shunt circuit, a radio frequency choke (RFC) is used. A radio frequency choke (RFC) has relatively little DC resistance and provides a large AC impedance, thereby keeping the oscillator signal from entering the power supply source. The choke also raises the DC collector working voltage. Remember AC entering a power source may cause interference with other circuits using the same voltage source. The technique of using the RFC as a collector load may also be used with the series-fed Hartley oscillator.

Several additional points concerning the two types of Hartley oscillators are necessary. First, the type of transistors used in the circuits may be either PNP or NPN and second, there are different ways to represent the circuits schematically other than those already shown in this lesson. Additional examples of Hartley type oscillator circuit schematics are show in Figure 8.



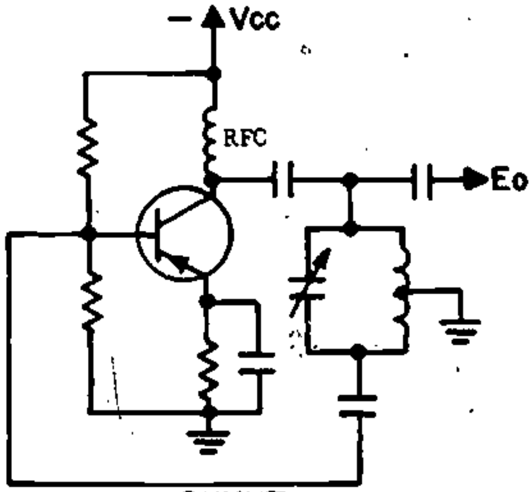


Figure 8

HARTLEY OSCILLATORS

A characteristic which is often used to distinguish Hartley type oscillators from other type oscillator circuits is the tank coil tap. After you determine that the tank coil is tapped, you can readily determine whether the oscillator is series or shunt by tracing the current flow through the transistor. In cases where the transistor current passes through the tank coil, the circuit is a Series-Fed Hartley. In instances where the tank circuit is connected in parallel, or in shunt with the transistor, the circuit is a shunt type Hartley oscillator.

Study the schematic and notice that the tank oscillations are reinforced by feedback through C3 and recall that once oscillation begins it continues as long as sufficient feedback is provided to compensate for the output power and internal power losses of the oscillator. After the oscillator begins to oscillate the base-emitter voltage of Q1 drops to less than 0.6 of a volt. In fact it may even become negative. The reason for this change is the charge on C1. C1 couples the tank circuit to the transistor base, thereby isolating the tank from the direct current of the biasing network. The capacitor develops a small voltage across it which opposes the transistor forward bias established by R1 and R2. The capacitor voltage opposes the positive base-emitter potential of transistor Q1. Recall that the conduction time of Q1 will determine the class of oscillator operation.

Since transistor current passes through Lc, this current flow increases the voltage drop across the coil and acts like a resistor in series with the coil. You likely recall that increasing the resistance of a tank coil reduces the Q of the coil and tank circuit. The one undesirable effect of this is that the tank bandwidth increases, thereby causing the oscillator to oscillate at a frequency other than originally intended.

Since frequency stability of an oscillator circuit depends on the Q of the oscillator tank, it is desirable to have an oscillator tank with a high Q. A high Q tank has good frequency stability, whereas a tank with a low Q has less stability. One method frequently used to increase frequency stability is to remove the DC current from the tank circuit. This is accomplished by moving the ground from the bottom of the tank to the emitter of Q1. This in effect removes the DC path from the tank. This is shown in the shunt type Hartley schematic in Figure 7.

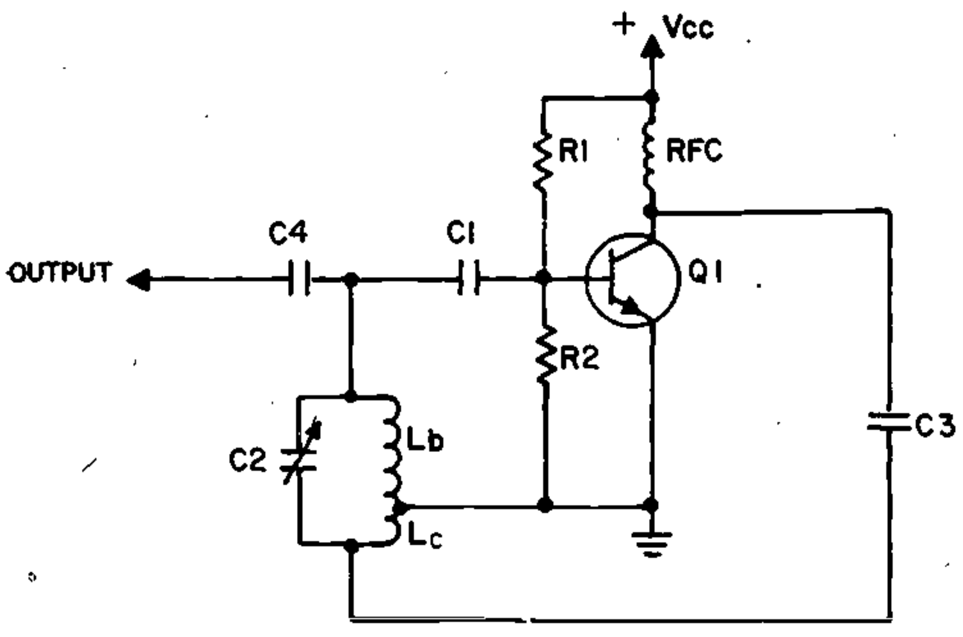


Figure 7

SHUNT-FED HARTLEY OSCILLATOR

BASIC ELECTRICITY AND ELECTRONICS

MODULE THIRTY TWO

LESSON 2

RC PHASE SHIFT OSCILLATOR

JULY 1980

As part of the job program associated with this lesson, you will be required to determine the operating frequency of an oscillator. Although you previously used an oscilloscope to determine oscillator frequencies you will now use a digital frequency counter. The frequency counter is much more accurate because it minimizes loading of the oscillator and provides a direct readout of the oscillator frequency. The accuracy of the counter is controlled by an internal crystal controlled oscillator. The accuracy of this type of test equipment approximates 1 part of 10^8 or 1 Hz in 100 MHz. The frequency counter which you will use as part of the job program is the AN/USM-207.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, PROCEED TO THE JOB PROGRAM. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH LEARNING CENTER INSTRUCTOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

32.2.57.6 MEASURE and COMPARE output waveforms and voltages of RC phase shift oscillator circuits, given a training device, circuit boards, test equipment and proper tools, schematic diagrams, and a job program containing reference data for comparison. Recorded data must be within limits stated in the job program.

32.2.57.7 IDENTIFY the faulty component or circuit malfunction in a given RC phase shift oscillator circuit, given schematic diagrams and failure symptoms, by selecting the correct fault from a choice of four. 100% accuracy is required.*

*FOOTNOTE: This objective is considered met upon successful completion of the Terminal Objective.

BEFORE YOU START THIS LESSON, READ THE LESSON LEARNING OBJECTIVES AND PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

OVERVIEW
LESSON 2

RC Phase Shift Oscillator

In this lesson you will learn about RC Phase Shift Oscillators and their application in electronic equipments. You will learn how phase shifting is accomplished through the use of the RC network, and become familiar with circuits which employ RC phase shift networks to sustain oscillation. You will learn about component functions in the RC oscillator and why this type of oscillator provides a stable frequency with a constant amplitude output signal.

The learning objectives of this lesson are as follows:

TERMINAL OBJECTIVE(S):

32.2.57 When the student completes this lesson, (s)he will be able to TROUBLESHOOT and IDENTIFY faulty components and/or circuit malfunctions in RC phase shift oscillator circuits when given a training device, prefaulted circuit board, necessary test equipment, schematic diagram, and instructions. 100% accuracy is required.

ENABLING OBJECTIVE(S):

When the student completes this lesson, (s)he will be able to:

32.2.57.1 IDENTIFY the factors required to sustain oscillations in an LC or RC oscillator circuit by selecting the correct statement from a choice of four. 100% accuracy is required.

32.2.57.2 IDENTIFY the basic principles by which phase shift is accomplished in an RC phase shift network by selecting the correct statement from a choice of four. 100% accuracy is required.

32.2.57.3 IDENTIFY the function of components and circuit operation of an RC phase shift oscillator circuit, given a schematic diagram, by selecting the correct statement from a choice of four. 100% accuracy is required.

32.2.57.4 IDENTIFY the methods by which the frequency of an RC phase shift oscillator can be changed by selecting the correct statement from a choice of four. 100% accuracy is required.

32.2.57.5 IDENTIFY the advantages of an RC phase shift oscillator by selecting the correct description of its characteristics from a choice of four. 100% accuracy is required.

SUMMARY
LESSON 2

RC Phase Shift Oscillator

When you previously studied LC oscillators you learned how the LC tank circuit and amplifier accomplish a 360 degree phase shift. You also learned that the purpose of this phase shift was to provide regenerative feedback for the oscillator circuit. Recall that the purpose of regenerative feedback is to compensate for internal power losses within the circuit and that without this feedback, the circuit will stop oscillating.

Other methods besides an LC tank circuit may be used in order to provide phase shifting. One such method for accomplishing the phase shift is to use a series of RC networks. Remember that an RC network is made up of a resistor and capacitor. Also recall that the ICE rule of thumb states that the current through a capacitor leads the voltage across it by 90 degrees. This means that a capacitor can cause a 90 degree phase shift. In actual application, however, this amount of shift cannot be realized. This is due to the fact that a resistance is required in the circuit in order to produce an output voltage. Therefore, when a capacitor is combined with the resistance, the maximum possible phase shift of the voltage across the resistor may approach 90 degrees but cannot equal it.

If you do not remember how phase shifting is accomplished by using an RC network, refer to lesson 2 of module 12. Since one phase shift network cannot accomplish a 90 degree phase shift, it is necessary to use three or more networks in order to achieve the necessary 180 degree shift. A minimum of three RC networks is generally used. The schematic diagram shown in Figure 1 depicts a 3-section RC phase shift network.

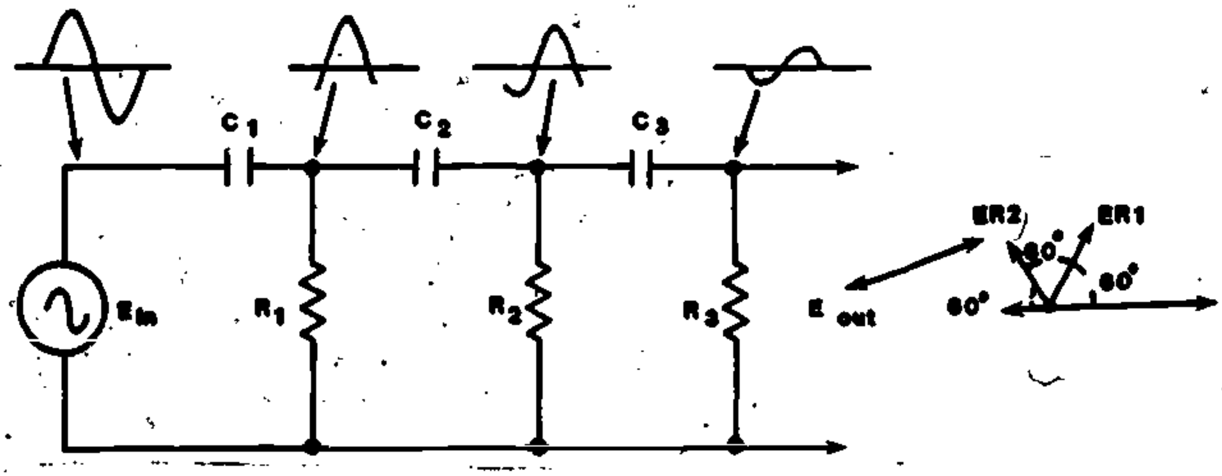


Figure 1

3-SECTION RC PHASE SHIFT NETWORK

LIST OF STUDY RESOURCES
LESSON 2

RC Phase Shift Oscillator

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following study resources:

Written Lesson presentation in:

Module Booklet:

Summary
Programmed Instruction
Narrative

Student's Guide:

Summary
Job Program Thirty Two-2 "RC Phase Shift Oscillator"
Progress Check
Fault Analysis (Paper Troubleshooting) I.S.
Performance Test I.S.

Additional Material(s):

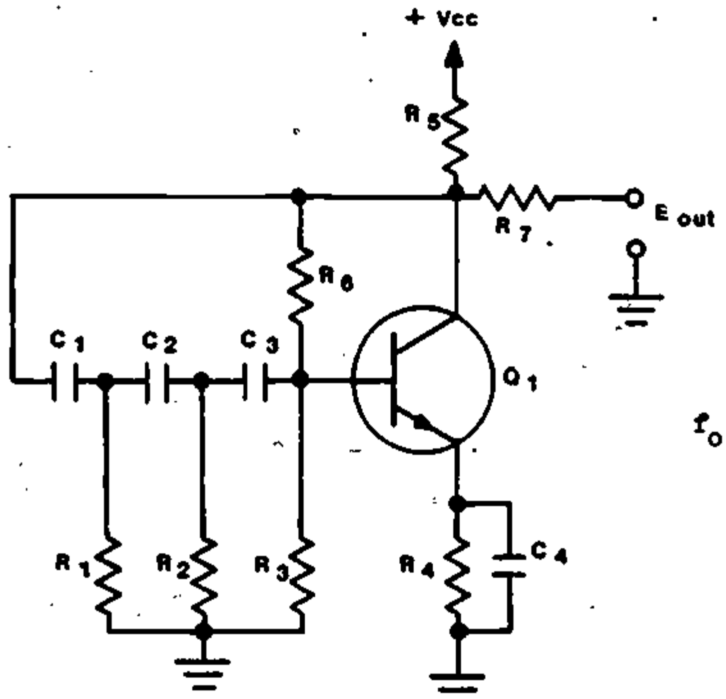
Audio/Visual Program Thirty Two-2 "RC Phase Shift Oscillator"

Enrichment Material(s):

Electronics Installation and Maintenance Book, EIMB, (Electronic Circuits)
NAVSHIPS 0967-000-0120

YOU MAY USE ANY, OR ALL, RESOURCES LISTED ABOVE, INCLUDING THE LEARNING CENTER INSTRUCTOR: HOWEVER, ALL MATERIALS LISTED ARE NOT NECESSARYILY REQUIRED TO ACHIEVE LESSON OBJECTIVES. THE PROGRESS CHECK MAY BE TAKEN AT ANY TIME.

The schematic diagram shown in Figure 2 is that of an RC phase shift oscillator circuit.



$$f_o = \frac{1}{2\pi RC\sqrt{6}}$$

Figure 2

RC PHASE SHIFT OSCILLATOR CIRCUIT

For ease in understanding, each of the networks shown in Figure 1 shows a 60 degree phase shift. In actual practice, each of the RC networks will accomplish phase shifts that are in the vicinity of 60 degrees. You may encounter a phase shift network of this type, where two of the networks effect a 75 degree phase shift and third network provides the additional 30 degrees of shifting. The most important thing for you to remember in regard to this is that the three networks combined accomplish the 180 degree shift. In addition to the schematic diagram, waveforms are shown immediately above each of the RC networks. These waveforms are used to illustrate the concept that the amplitude and phase of the input voltage is modified by each of the RC networks. The waveforms show that the amplitude decreases with each succeeding RC network. In addition to the waveforms, vectors are shown immediately to the right of the schematic diagram. These vectors also indicate the change of magnitude and phase shift provided by each RC network. Even though a 60 degree phase shift is indicated, remember, in actual practice, the phase shift may be somewhat more or less than the 60 degrees shown. Also recall that the total shift must be 180 degrees. You will sometimes encounter four section networks, and these networks provide approximately 45 degrees of phase shift per network.

The schematic diagram shown in Figure 3 is that of a variable frequency RC phase shift oscillator.

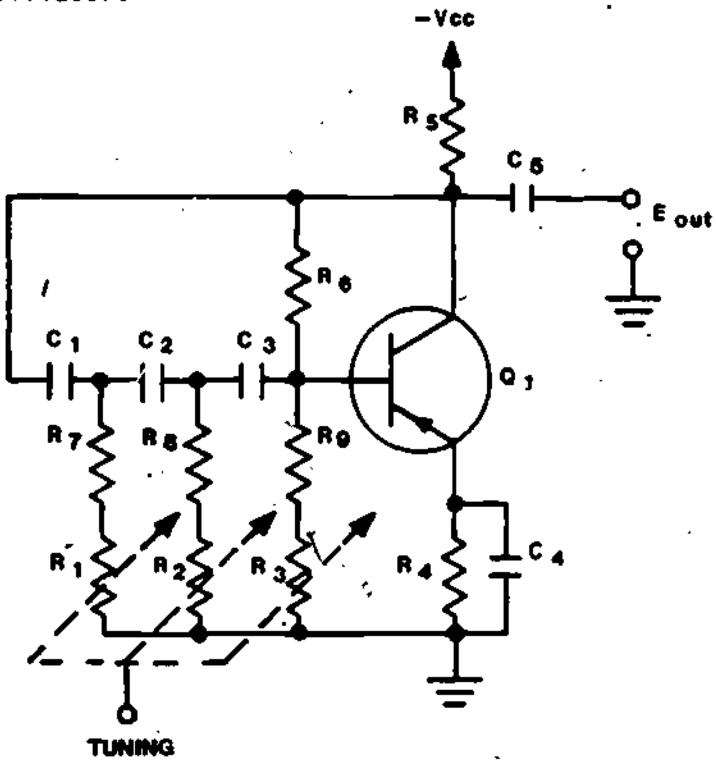


Figure 3

VARIABLE FREQUENCY RC PHASE-SHIFT OSCILLATOR

The addition of the ganged variable resistor allows the output frequency to be varied over a limited range. Notice that the variable resistors are part of the resistance of the phase shift network. Another technique which is sometimes used to vary the oscillator output frequency is to use ganged variable capacitors. Remember, the actual oscillating frequency of the oscillator may be determined by substituting in the formula: $F_0 = \frac{1}{2\pi RC\sqrt{6}}$. In this example, the values of each of the RC networks is identical.

The oscillator circuit shown in Figure 3 provides a pure, nondistorted sinusoidal output waveform. Because there is no LC tank circuit to smooth the sine wave output, the oscillator must be operated in Class A service on the linear operating region for the transistor.

You will have an opportunity to work with an RC oscillator type circuit when you use the NIDA oscillator as part of your job program for this lesson.

The circuit shown accomplishes a 360 degree total phase shift from base, to collector, to base. The RC network accomplishes 180 degrees of the shift, whereas transistor Q1, in addition to amplifying the signal, contributes the other 180 degrees of phase shift. The amount of amplification provided by the transistor depends on the transistor's voltage gain.

The phase shifting network of the schematic shown in Figure 2 consists of resistors R1, R2, R3 and capacitors C1, C2 and C3. Although each RC section is capable of providing approximately 60 degrees of phase shift, in actual practice the phase shift provided by each of the networks may vary. Nevertheless, the three networks together provide a combined shift of 180 degrees. Components other than those which make up the RC network are for a standard common emitter type amplifier. Forward bias for the transistor is provided by the voltage divider from V_{CC} to ground through resistors R3, R5, and R6. This resistance network establishes a voltage at the base of Q1 at about 0.6 volts positive in respect to the ground. In addition, a small amount of negative feedback is introduced by connecting R6 between the collector and base of Q1. This degenerative feedback improves the purity of the sinewave output signal. R5 functions as the collector load resistor for Q1, whereas the R4-C4 combination provides emitter stabilization action for the transistor. Resistor R7 couples a portion of the collector's signal of Q1 to the output terminals and isolates the oscillator from the load. Concerning this type of circuitry, it is possible to use either NPN or PNP transistors. The output of this oscillator circuit must be sufficient to provide a regenerative signal of adequate magnitude to compensate for internal power losses of the oscillator. As you undoubtedly know, if this is not provided, the oscillator will stop oscillating.

The output frequency of RC oscillators may be changed by changing the values of the resistors and capacitors which make up the individual RC networks. Increasing the resistance or capacitance of the components which make up the network results in a decrease in the output frequency. Conversely, a decrease in the resistance or capacitance of the network components results in an increase in the output frequency. This relationship is shown by the formula for the oscillating frequency.

PROGRAMMED INSTRUCTION
LESSON 2

RC Phase Shift Oscillator

TEST FRAMES ARE 2, 7, 11, AND 17. PROCEED TO TEST FRAME 2 AND SEE IF YOU CAN ANSWER THE QUESTIONS. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

1. When you previously studied LC oscillators, you learned how the LC tank circuit and amplifier accomplish a 360 degree phase shift. You learned that the purpose of this phase shift was to provide regenerative feedback for the oscillator circuit. Remember that the purpose of the regenerative feedback is to compensate for internal power losses within the circuit and that without this feedback the circuit will stop oscillating. The requirements for a basic LC oscillator circuit are shown pictorially in Figure 1.

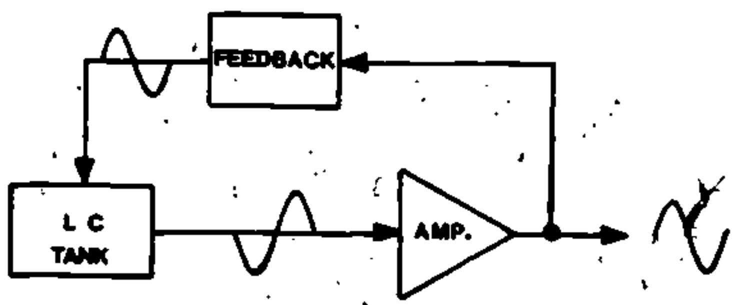


Figure 1
BASIC LC OSCILLATOR

In this example the tank circuit determines oscillator frequency and provides a 180 degree phase shift. The phase shift is shown by the waveforms in the diagram.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, PROCEED TO THE JOB PROGRAM. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH THE LEARNING CENTER INSTRUCTOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

2. THIS IS A TEST FRAME. AFTER YOU ANSWER THE QUESTIONS, COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS ON THE TOP OF THE PAGE FOLLOWING THE QUESTIONS.

1. In a basic LC oscillator circuit, the LC tank and amplifier each provide _____ degrees of phase shift.
   a. 60
   b. 90
   c. 180
   d. 360

2. To sustain oscillation, the feedback in an oscillator circuit must be
   a. neutral.
   b. degenerative.
   c. superlative.
   d. regenerative.

3. Oscillator feedback is necessary in order to
   a. compensate for internal circuit power losses.
   b. provide damping for the oscillator.
   c. provide a forward bias for the oscillator transistor.
   d. compensate for power surges.

In addition to providing the required amount of feedback, the amplifier circuit provides an additional 180 degrees of phase shift to make the feedback in phase with the tank voltage.

In a basic LC oscillator circuit, the tank circuit and amplifier circuit each provide ________ degrees of phase shift.

a. 90

b. 120

c. 180

d. 360

---

c. 180

69

1. c. 180 degrees
2. d. Regenerative
3. a. Compensate for internal circuit power losses

IF YOUR ANSWERS MATCH THE CORRECT ANSWERS GIVEN ABOVE YOU MAY GO TO TEST FRAME 7. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAM SEQUENCE AGAIN BEFORE TAKING TEST FRAME 2 AGAIN.

3. Another method for accomplishing a phase shift is to use a series of RC networks. In module 12 you learned that an RC circuit has the capability of shifting the phase of the voltage across the circuit components. Remember that in a series resistive-capacitive circuit, current leads the applied voltage. Stated in very simple terms, E_R leads E_{in} by some phase angle. It is possible for one RC network to effect <u>almost</u> 90 degrees of phase shift, between E_R and E_{in}. The reason why 90° of phase shift cannot be achieved is that a minimum circuit resistance in series with the capacitor is required to develop a usable phase shift voltage.

The maximum amount of phase shift possible with a single RC network is almost ______ degrees.

a. 45

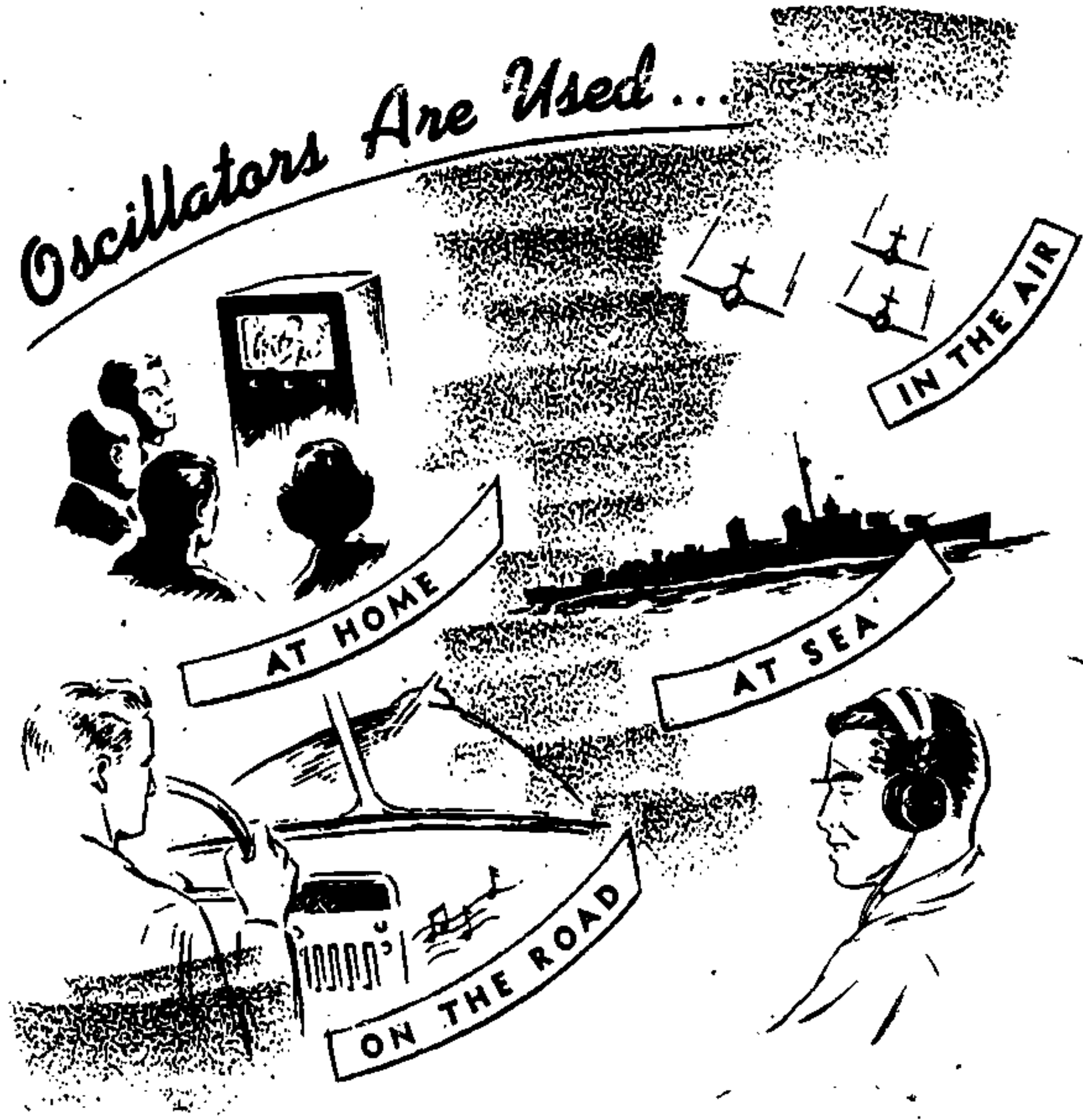
b. 60

c. 90

d. 180

---

c. 90


Oscillators Are Used ...
AT HOME
IN THE AIR
AT SEA
ON THE ROAD

b. decreased

5. Since 90° of phase shift cannot be provided with a single RC network, three or more RC networks must be used to accomplish 180° of shift. The actual amount of phase shift provided by each individual network is dependent on the value of the resistor and capacitor of that particular network. The total phase shift provided by a series of networks is equal to the sum of the phase shifts of each individual network. The schematic diagram shown in Figure 3 is a schematic for a two-section phase shift network. This network is shown even though in actual practice a 180 degree phase shift could not be accomplished using only two networks.

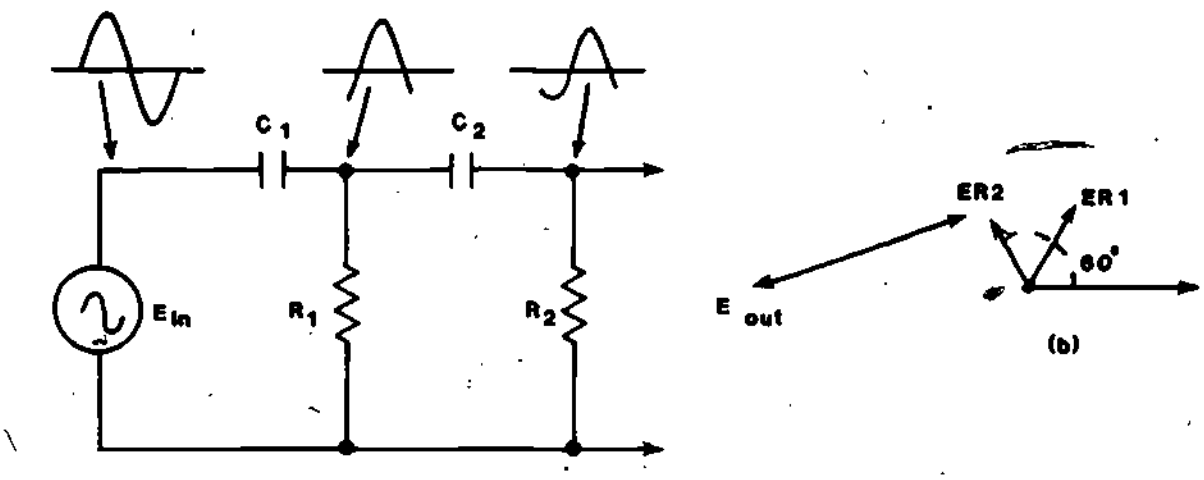
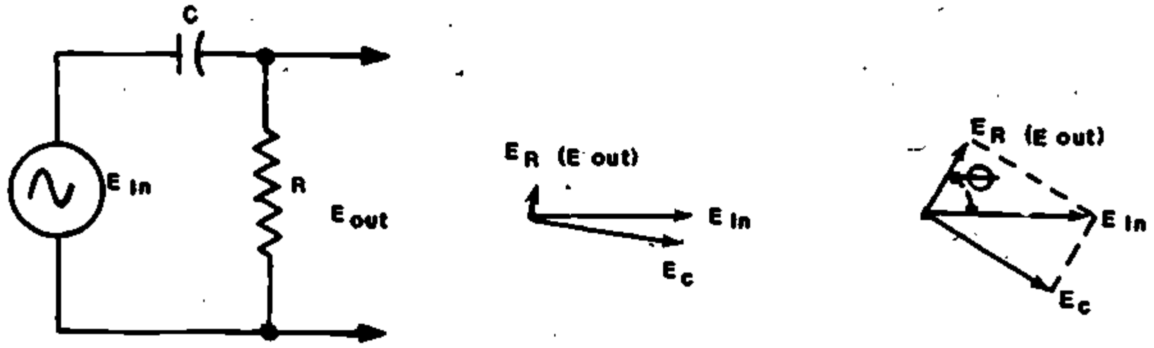


Figure 3

2-SECTION RC PHASE SHIFT NETWORK

Next to the schematic diagram are vectors showing the relative amount of output in each phase. Notice that the output voltage at R1 is less than the input voltage at E_{in}, and the output at E_{R2} is still less than the output shown at E_{R1}. Although a total phase shift of 120 degrees for the two networks is indicated, in an actual application it could be somewhat more or less.

4. A single RC phase shift circuit is shown in Figure 2. In addition to the schematic, two sets of vectors are shown.



SINGLE RC NETWORK

LARGE PHASE SHIFT (E_R TO E_{in})

PRACTICAL PHASE SHIFT (E_R TO E_{in})

Figure 2

The vectors immediately to the right of the schematic show a large amount of phase shift with a single RC network. The vectors shown at the far right side of the Figure show a more practical phase shift with a single RC network. Notice that as the phase shift angle approaches 90 degrees (E_R to E_{in}) the amplitude of E_R becomes less. The E_R vector approaches zero volts as the phase angle between E_R and E_{in} approaches 90°. The amount of phase shift possible using <u>one</u> RC network is <u>always</u> less than (<) 90°.

As the phase angle between E_R and E_{in} increases, the amplitude of E_R is ______.

a. increased

b. decreased

c. doubled

d. square

---

6. Figure 4 shows a three-section RC phase-shift network.

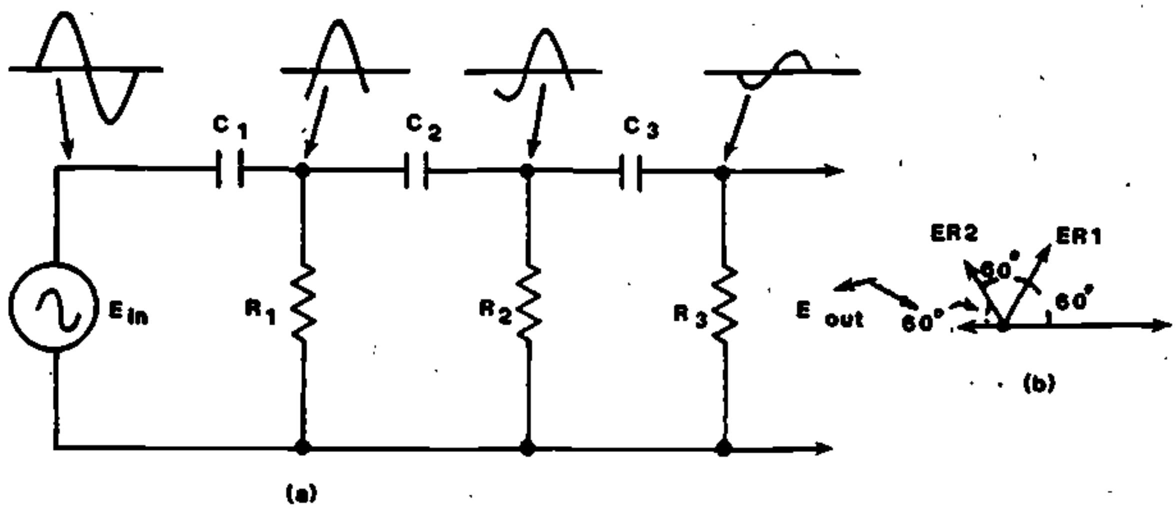


Figure 4

THREE-SECTION RC PHASE-SHIFT NETWORK

Since it is impossible for a single RC network to provide 90 degrees of phase shift, it is also impossible for two networks to provide a total of 180 degrees of phase shift. For this reason at least three RC networks must be used in order to accomplish a 180 degree phase shift.

In order to accomplish a 180 degree phase shift, a minimum of ______ RC network(s) must be used.

a. one

b. two

c. three

d. four

---

c. three

7. THIS IS A TEST FRAME. AFTER YOU ANSWER THE QUESTIONS, COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE PAGE FOLLOWING THE QUESTIONS.

1. When a group of RC networks are connected in series, the total phase shift of the networks is equal to the _____ of the individual network phase shifts.

   a. product

   b. difference

   c. square

   d. sum

2. The output waveform amplitude of an RC phase shift network is ______ with each successive RC stage.

   a. increased

   b. rectified

   c. held constant

   d. reduced

Phase-shift waveforms are shown immediately above each RC network in Figure 4. Amplitude reduction is also indicated by the varying size of the waveform. Remember, output amplitude decreases with each RC network. In this example, the amplitude of the output at R3 is considerably less than the signal initially applied to the circuit at E_{in}. Although the vectors and waveforms are not drawn exactly to scale, they do illustrate the concept of amplitude reduction and phase shift.

In the example, a phase shift of 60 degrees for each network is indicated.

Although the waveforms and vectors indicate that each network provides a 60 degree phase shift, in actual practice the phase shift of each of the RC networks will vary. However, the total phase shift of three networks connected in series is 180 degrees. For example, if R1-C1 and R2-C2 each effect a phase shift of 70 degrees, then the combination R3-C3 will provide an additional 40 degrees of phase shift.

If two sections of a three section series-connected RC network provide 50 degrees and 60 degrees of phase shift respectively, the third section must provide ______ degrees of phase shift to achieve a total 180 degree shift.

a. 60

b. 70

c. 80

d. 90

---

b. 70

1. d. sum
2. d. reduced
3. d. 60 degrees
4. a. C1-R1

IF YOUR ANSWERS MATCH THE CORRECT ANSWERS GIVEN ABOVE, YOU MAY GO TO TEST FRAME 11. IF YOUR ANSWERS DO NOT MATCH, GO BACK TO FRAME 3 AND TAKE THE PROGRAM SEQUENCE AGAIN BEFORE TAKING TEST FRAME 7 AGAIN.

8. The frequency which produces 180° of phase shift in RC networks may be varied by changing the value of the network resistors or capacitors. Recall that the total phase shift of a series of RC networks is the sum of the phase shift of each individual network.

The schematic diagram shown in Figure 5 shows four RC networks connected in series. In this case each of the networks contributes approximately 45° of phase shift. RC phase shift networks with more than four sections are seldom used. The primary advantage of using additional RC networks is increased circuit stability.

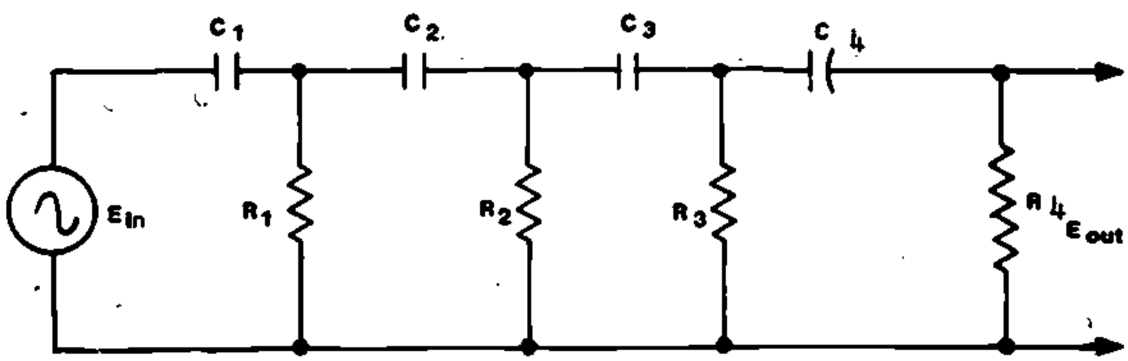
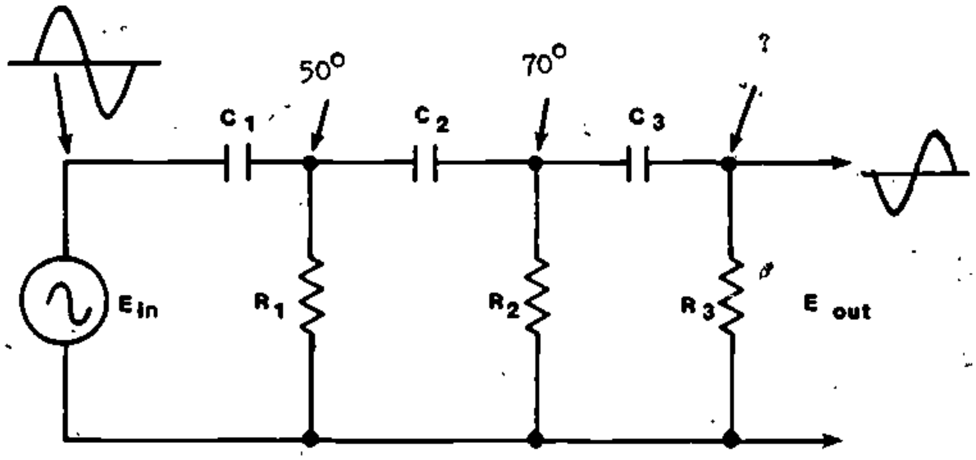


Figure 5

FOUR-SECTION RC NETWORK

REFER TO THE SCHEMATIC SHOWN BELOW WHEN ANSWERING QUESTIONS 3 AND 4.



3. The phase shift provided by the network R3-C3 is _______ degrees.

   a. 90

   b. 80

   c. 70

   d. 60

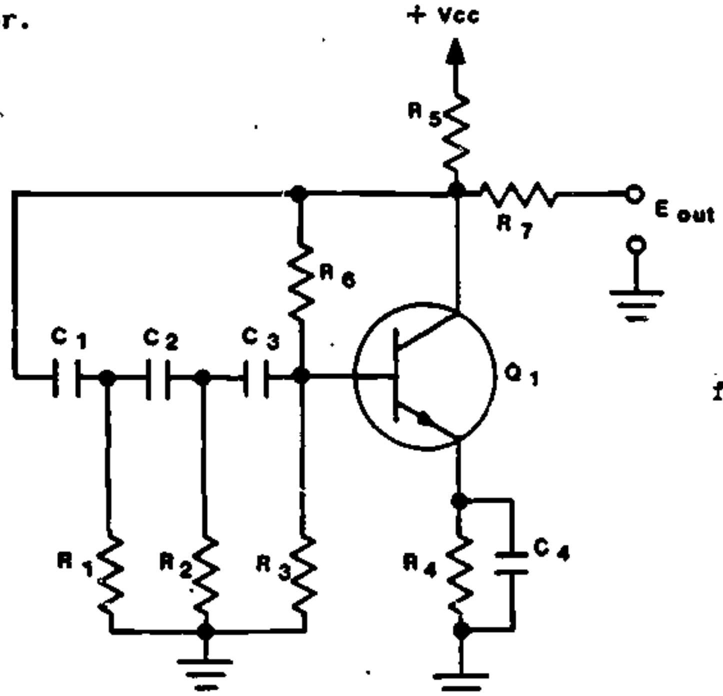
4. With the input waveform shown, the maximum signal amplitude occurs at the junction of

   a. C1-R1

   b. C2-R2

   c. C3-R3

9. The schematic diagram shown in Figure 6 is that of an RC phase shift oscillator.



$$f_0 = \frac{1}{2\pi RC\sqrt{6}}$$

Figure 6

RC PHASE SHIFT OSCILLATOR CIRCUIT

The main advantage of using more than three RC networks to effect a phase shift is

a. more components can be used.

b. increased circuit stability.

c. less voltage is required.

d. DC can be used.

---

b. increased circuit stability

R5 is the collector load resistor for the transistor.

Each of the RC networks shown in Figure 6 provides approximately _____ degrees of phase shift and the transistor provides an additional _____ degrees of phase shift.

a. 60, 90

b. 60, 180

c. 45, 90

d. 45, 180

---

b. 60, 180

In this case, the phase shifting network consists of resistors R1, R2, and R3 and capacitors C1, C2 and C3. This circuit uses the minimum number of three RC networks to effect a 180 degree phase shift. The remaining 180 degree phase shift is accomplished by the amplifier Q1. Notice that these components make up a standard, common emitter type amplifier. The amplifier circuit, by the inverting action of Q1, produces the additional 180 degrees of phase shift required for oscillation to occur. The RC network and Q1 each provide 180 degrees of phase shift. A total shift of 360 degrees is therefore provided by this circuit.

Transistor Q1 provides _____ degrees of phase shift.

a. 45

b. 90

c. 120

d. 180

---

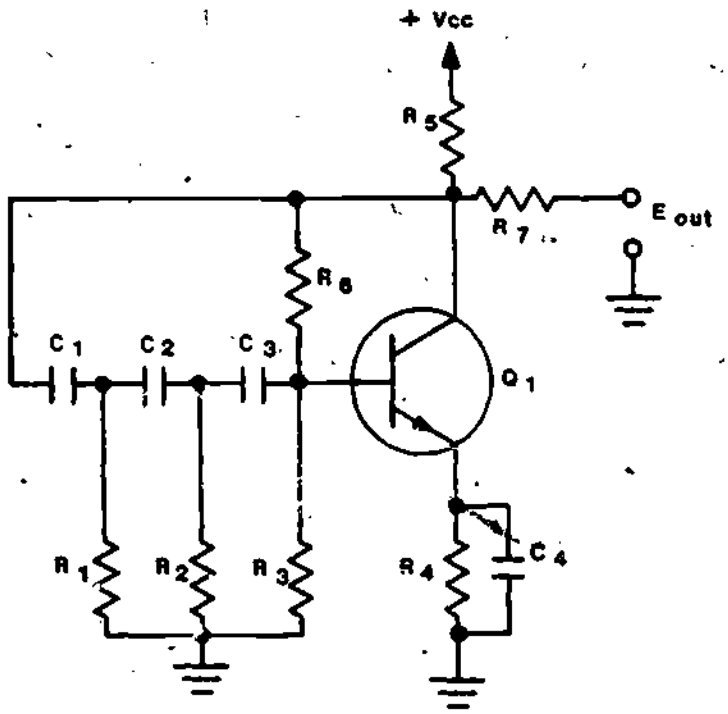
d. 180

(10.) Refer again to the schematic shown in Figure 6. In this case, Q1 amplifies the signal applied to its base and provides a 180 degree out-of-phase signal at its collector. Class A operation of the circuit is secured by R5, R6 and R3 which provide about 0.6 V forward bias for Q1.

R4 and C4 provide the necessary emitter stability for the transistor. R6 is connected to the collector of Q1 vice Vcc. This arrangement introduces a small amount of degenerative feedback to the circuit to improve the purity of the output waveform.

(II.) THIS IS A TEST FRAME. AFTER YOU ANSWER THE QUESTIONS, COMARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE PAGE FOLLOWING QUESTIONS.

REFER TO THE SCHEMATIC BELOW WHEN ANSWERING THE TEST QUESTIONS.

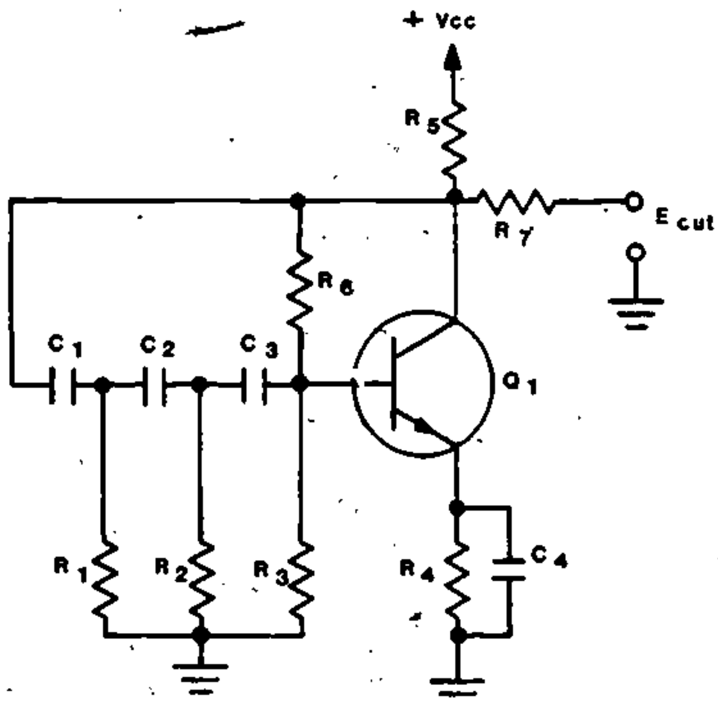



THEY ALL NEED
OSCILLATORS

1. c. three
2. d. 180, 60
3. c. increases circuit stability

IF YOUR ANSWERS MATCH THE CORRECT ANSWERS GIVEN ABOVE, YOU MAY GO TO TEST FRAME 17. IF YOUR ANSWERS DO NOT MATCH, GO BACK TO FRAME 8 AND TAKE THE PROGRAMMED SEQUENCE AGAIN BEFORE TAKING TEST FRAME 11 AGAIN.

(12) Refer to the schematic shown in Figure 7.



$$f_o = \frac{1}{2\pi RC\sqrt{6}}$$

Figure 7

RC PHASE SHIFT OSCILLATOR CIRCUIT

1. The ocillator circuit RC phase-shift network is made up of ______ individual RC section(s).
   a. one
   b. two
   c. three
   d. four

2. Q1 provides _____ degrees of phase shift and each of the networks provides approximately _____ degrees of shift.
   a. 90, 60
   b. 180, 45
   c. 90, 90
   d. 180, 60

3. The number of RC networks in a 180° phase-shift circuit may be increased in order to
   a. use additional components.
   b. reduce the amount of input voltage required.
   c. increase circuit stability.
   d. create a larger phase shift.

The output waveform of an RC oscillator is a ________ wave

a. square

b. sawtooth

c. sine

d. peak

---

c. sine

14. The output frequency of an RC oscillator may be changed by changing the resistor or capacitor values of the individual networks which make up the phase shift part of the oscillator. The schematic shown in Figure 8 is that of a variable frequency RC phase shift oscillator.

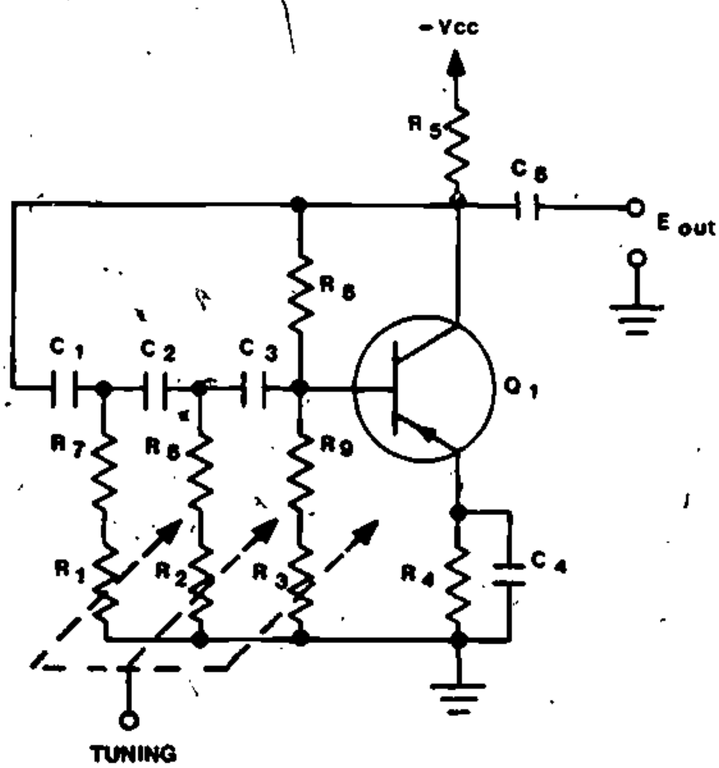


Figure 8

VARIABLE FREQUENCY PHASE-SHIFT OSCILLATOR

When power is applied, current flows through the circuit components and Q1. This current flow generates a type of electronic signal called "noise." This noise signal is felt on the base of Q1, amplified, and shifted 180 degrees on the collector of the transistor. Because the noise signal contains a number of frequencies, it is sometimes called "random in frequency."

A signal which contains a large number of random frequencies is often referred to as a ____________ signal.

"noise"

(13) Refer again to the schematic in Figure 7. The signal from Q1's collector is now fed through the RC phase-shift network and one of the noise frequencies is selected and shifted 180°, and returned to the base of Q1. This signal is in phase with the original input signal due to the total circuit phase shift. At this time oscillation begins, the frequency is amplified and the cycle is repeated. Whenever this happens the signal amplitude is increased until finally a stable operating level is reached. The amplitude or operating level of the output signal, is determined by the transistor gain, Vcc, RC values, and other components which make up the circuit. The output approximates the sine wave developed by a good audio signal generator which you have seen on an oscilloscope.

RC phase-shift oscillators provide stable sine wave output frequencies in the 15 Hz to 200 kHZ range. The kHZ actual output frequency may be computed by substituting values in the formula: $F_o = \frac{1}{2\pi RC\sqrt{6}}$, where R and C are the values of identical phase shift sections. Notice the inverse relation between R-C values and the oscillating frequency. If R and C are increased the oscillating frequency decreases.

Because the RC phase shift circuit has no tuned resonant circuitry, it is less likely to ________________.

a. oscillate

b. damp

c. drift

d. shift phase

---

c. drift

(17.) THIS IS A TEST FRAME. AFTER YOU ANSWER THE QUESTIONS, COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN ON THE TOP OF THE PAGE FOLLOWING THE QUESTIONS.

1. An RC phase shift oscillator provides a ___________ wave output.

   a. sine

   b. saw tooth

   c. peak

   d. square

2. The output frequency of a RC phase shift oscillator may be increased by ________ the value of the resistors or capacitors used in the ________ network.

   a. decreasing, decoupling

   b. decreasing, phase shift

   c. increasing, decoupling

   d. increasing, phase shift

In this example, variable ganged resistors are used to change the oscillator output frequency. It is also possible to vary the output frequency by using ganged variable capacitors. Again refer to the schematic in Figure 9. By increasing the resistance of R1, R2, and R3 the output frequency is reduced. Reducing the values of the RC network resistors will increase the output frequency of the oscillator.

The output frequency of a variable frequency RC phase shift oscillator may be increased by ____________ the value of the variable resistors.

---

decreasing

(15.) Again refer to the schematic shown in Figure 9. When the value of capacitors C1, C2, and C3 is increased, the frequency of the oscillator is decreased. Of course reducing capacitance will increase the frequency of the oscillator. Study the schematic and make sure you understand how changing the values of the RC network resistors and capacitors effects output frequency. Notice that a PNP type transistor works just as well as the NPN type.

The output frequency of an RC phase shift oscillator may be varied by ____________

---

changing the values of the RC network resistors and capacitors

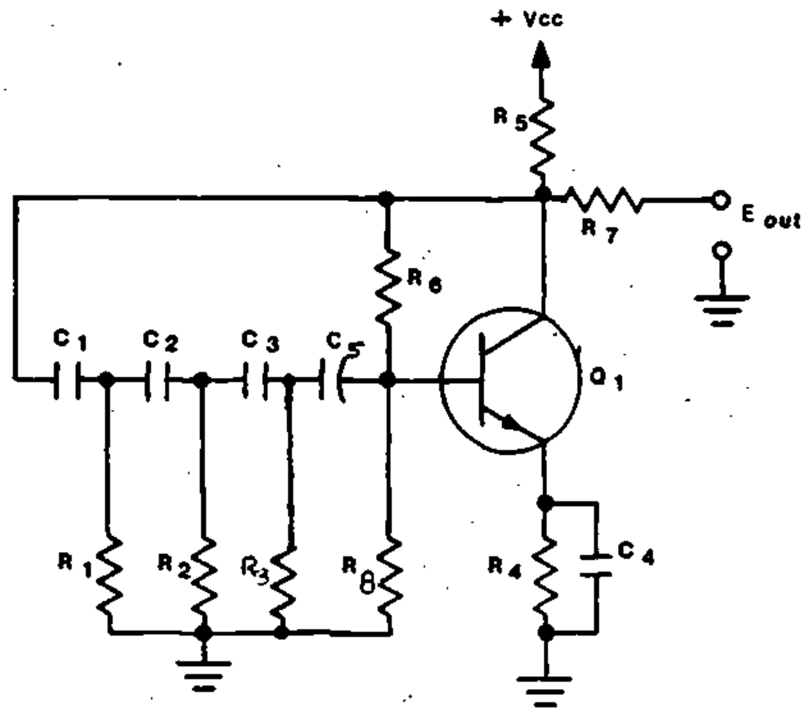
(16.) RC phase shift oscillators have several advantages over other types of oscillators. Besides being simple, lightweight, and inexpensive, the RC phase shift oscillator is very stable. This is due to the fact that the circuit has no tuned resonant circuits and, therefore, is not as susceptible to detuning or drifting.

1. a. sine
2. b. decreasing, decreasing
3. b. increase

IF YOUR ANSWERS MATCH THE CORRECT ANSWERS YOU HAVE COMPLETED THE PROGRAMMED INSTRUCTION FOR LESSON 2, MODULE THIRTY TWO. OTHERWISE GO BACK TO FRAME 12 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 17 AGAIN.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, PROCEED TO THE JOB PROGRAM. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH THE LEARNING CENTER INSTRUCTOR UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

REFER TO THE SCHEMATIC BELOW WHEN ANSWERING QUESTION 3.



3. If C2 decreases, assuming oscillations continued, the output frequency would

a. remain the same.

b. increase.

c. decrease.

The drawing shown in Figure 2 illustrates how the LC tank circuit effects the phase shift. This 180° phase shift is comparable to the phase shift resulting from transformer action.

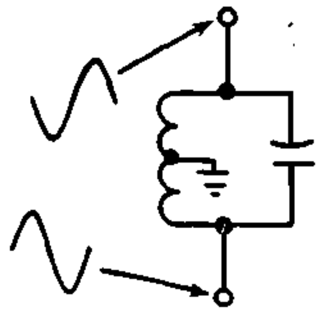


Figure 2

TANK CIRCUIT PHASING

Recall that in phase or regenerative feedback to the tank is required in order for oscillation to take place. The feedback must also be of sufficent magnitude to compensate for power losses in the tank and the oscillator circuit.

Although regenerat ve feedback is necessary to trigger and sustain oscillation, the LC tank oscillator is not the only circuit used to accomplish phase shifting and frequency selection. The phase shifting properties of a series of RC networks may be used. A simple, single RC network is shown in Figure 3.

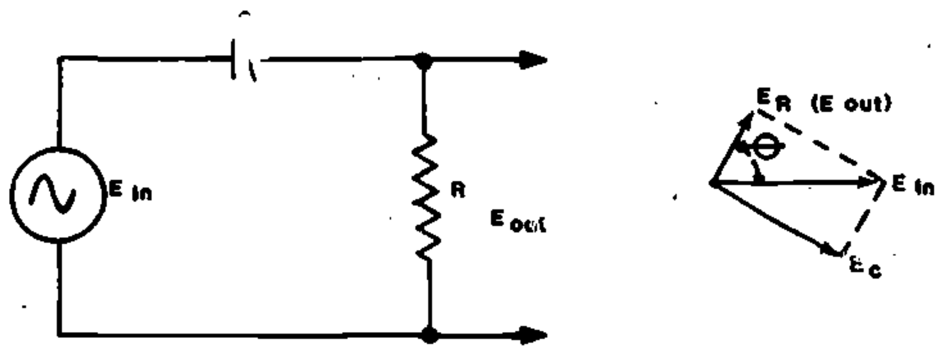


Figure 3

RC PHASE-SHIFT CIRCUIT

The RC phase shift network has several advantages over the LC tank. Besides being simple, lightweight, and inexpensive, it is also very stable. Because it has no resonant circuit, it is less susceptible to detuning or drifting.

NARRATIVE
LESSON 2

RC Phase Shift Oscillator

In your previous study of oscillators you learned that there are three essential requirements for each LC oscillator circuit. Each LC oscillator has a tank circuit, an amplifier circuit and provision for regenerative feedback. This is illustrated pictorially in Figure 1.

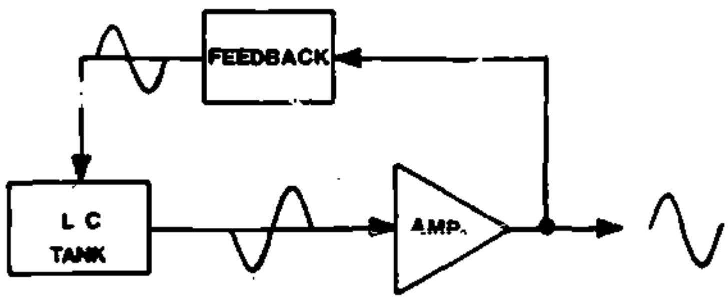


Figure I

BASIC LC OSCILLATOR

Pay particular attention to the waveforms shown in the drawing. Notice that both the amplifier and LC tank invert the waveform 180°. These combined phase inversions result in a total 360° phase change. As a result, the part of the amplifier output, which is returned to the tank c'cuit, is in phase with the tank signal. This regenerative feedback compensates for power losses within the tank circuit. If sufficent regenerative feedback is not provided to compensate for the power loss, the tank will cease oscillating.

In addition to the schematic diagram vectors showing the amount of output at each phase are shown. Notice that the output voltage at R1 is less than the input voltage at E_{in} and that the output at E_{R2} is still less than the output at L_{RI}. In this example, a 120° phase shift is shown, 60° for each section. Notice that the output from R1 becomes the input to the second network composed of R2 and C2. Study the vectors associated with Figure 4 and notice the decrease in signal amplitude as the signal passes through the RC network. If you have concluded that the decrease in amplitude must be compensated for, you are correct. Of course, the method used to compensate for this decrease is to use an amplifier with sufficient gain to provide the required regenerative feedback voltage.

In order to accomplish a 180° phase shift, it is necessary to connect a minimum of three RC phase shift networks in series. Such a circuit configuration is shown in Figure 5.

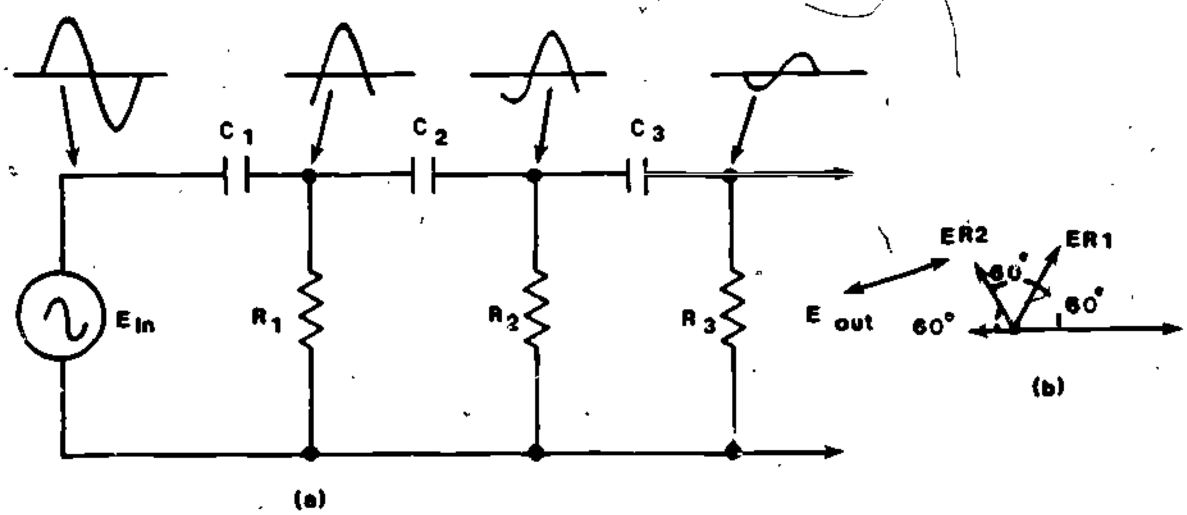


Figure 5

THREE SECTION RC PHASE-SHIFT NETWORK

In addition to showing the circuit configuration, phase shift waveforms at various stages are indicated immediately above the RC networks. Notice particularly that the amplitude of the output across R3 is significantly less than the signal initially applied to the circuit at E_{in}. The vectors shown on the right hand side of the drawing indicate the amount of phase shift accomplished by each of the RC networks and also show the reduction in amplitude. Notice that in the drawing each RC network shifts the phase of the voltage applied to it approximately 60°. Therefore, the three sections produce a total of 180° of phase shift. In actual practice, the phase shift of each RC network may vary, however, the total phase shift of the three networks

In Module 12 you learned that an RC circuit has the capability of shifting the phase of the voltage across the circuit components. Recall that in a series resistive capacitive circuit, the current leads the voltage across the capacitor by 90°. Stated quite simply E_R leads E_C by 90°.

Although it is theoretically possible for one RC network to effect almost 90° of phase shift, this is not true in actual practice. The reason for this is that a minimum circuit resistance is necessary to develop a usable phase shifted voltage.

Because a 90° phase shift cannot be effected with a single RC network, at least three RC networks must be used to cause the required 180° phase shift. The amount of phase shift provided by each network is dependent on the value of the resistor and capacitor of the network in relation to the applied frequency. The total phase shift of the networks is equal to the sum of the phase shifts of each individual network.

The schematic diagram shown in Figure 4 is for a two section phase network. Although a two section RC network cannot achieve a 180° phase shift, understanding how the two section RC network works will help you understand the theory of RC network operation.

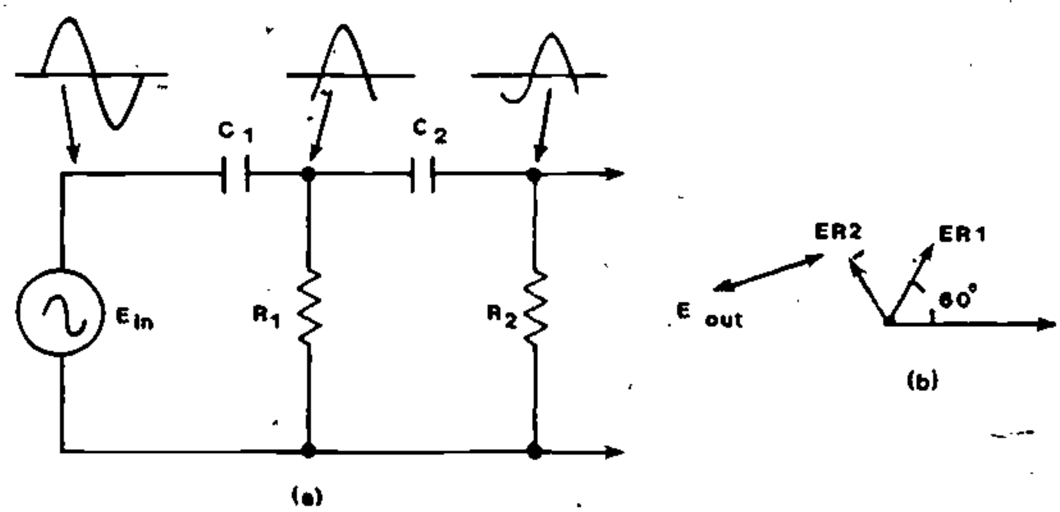


Figure 4

TWO SECTION RC NETWORK

emitter stabilization action for Q1. R7 couples a portion of the collector signal of Q1 to the output terminals. The DC collector voltage on Q1 is approximately one-half the value of V_{CC} for class A operation. The signal applied to the base of Q1 results in a 180° out-of-phase signal on the Q1 collector. Since the RC network provides a 180° phase shift and because Q1 provides an additional 180° phase shift, the total phase shift provided by this circuit is 360°. When power is applied, current flows through Q1. This current generates a type of electronic signal called "noise". Noise contains many frequencies but only one is the desired frequency. The noise signal, at the base of Q1, is amplified and shifted 180° to the collector of Q1. The noise signal from the collector of Q1 is then fed through the RC phase shift network. The RC phase shift network shifts the desired frequency exactly 180° and provides an in-phase signal to the base of the transistor. At this point the oscillation process begins and the single noise frequency is again amplified, shifted in phase by Q1 and fed through the three RC phase shift networks. This sequence is repeated until the amplitude of the signal is increased and a stable operating level is reached. The operating level is determined by the gain of the transistor, the RC values, and other variables. The output of this circuit is a sine wave frequency which is almost pure in form. It approximates the sine wave generated by an audio signal generator which you have observed on an oscilloscope.

RC phase shift oscillators are normally used to provide stable, fixed frequency sine wave output signals in the 15 Hz to 200 kHz range. The actual frequency of operation may be determined by the followng formula: $Fo = \frac{1}{2\pi RC\sqrt{6}}$, where three identical phase shift sections are used.

The frequency of RC oscillators may be changed by changing the values of the resistors and capacitors which make up the RC networks. If either the resistance or capacitance of the components in the phase shift section are increased, the output frequency decreases. A decrease in the resistance or capacitance of the RC phase shift network components results in an increase in the output frequency.

connected in series is 180°. For example, if networks R1-C1 and R2-C2 each provided 75° of phase shift the R3-C3 network would provide the remaining 30° of shift necessary for a total 180° shift. Some RC phase shift oscillators use four RC networks to accomplish a 180° shift. In this case, each RC network produces approximately 45° of phase shift. RC phase shift networks with more than four sections are seldom used. The advantage of using more RC networks is increased stability.

The schematic shown in Figure 6 is that of an RC phase shift oscillator.

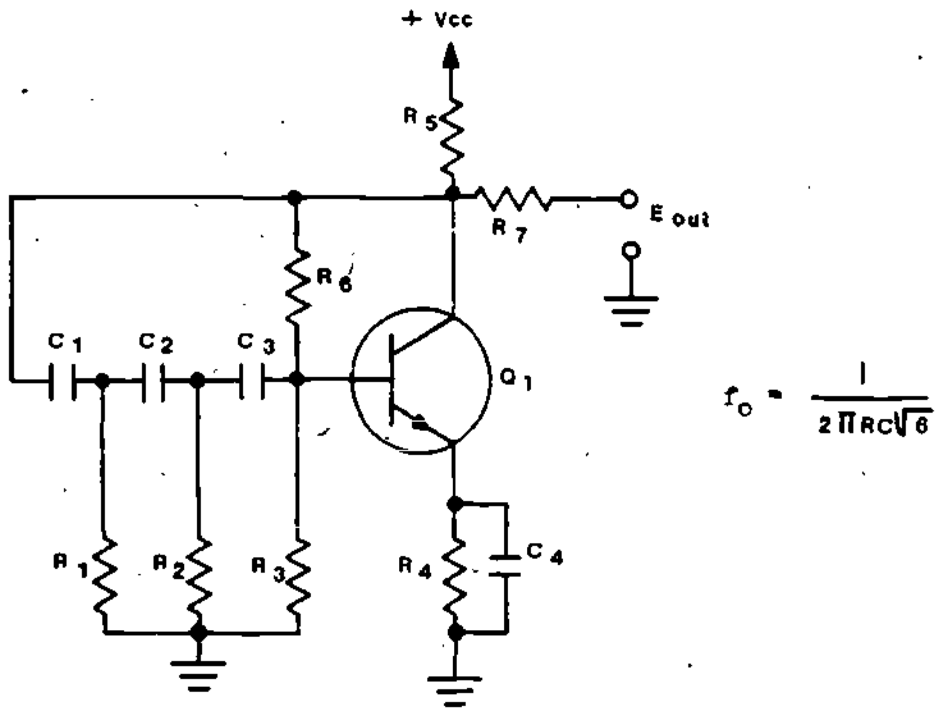


Figure 6

RC PHASE SHIFT OSCILLATOR CIRCUIT

The phase shifting network of this circuit consists of equal value resistors R1, R2, R3, and equal value capacitors C1, C2, C3. In this example, each section produces approximately 60° of phase shift. The remaining circuit components make up a standard common emitter amplifier. Let's briefly review the function of these components. Forward bias for the transistor is provided by the voltage divider from V_{CC} to ground through R5, R6 and R3. This resistance network establishes a voltage on the base of Q1 at about .6 volts positive with respect to ground. R5 acts as the collector load resistor for Q1, and R4-C4 provides

AT THIS POINT YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECLTY, PROCEED TO THE JOB PROGRAM. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH THE LEARNING CENTER INSTRUCTOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

The schematic shown in Figure 7 is that of a variable frequency RC phase shift oscillator.

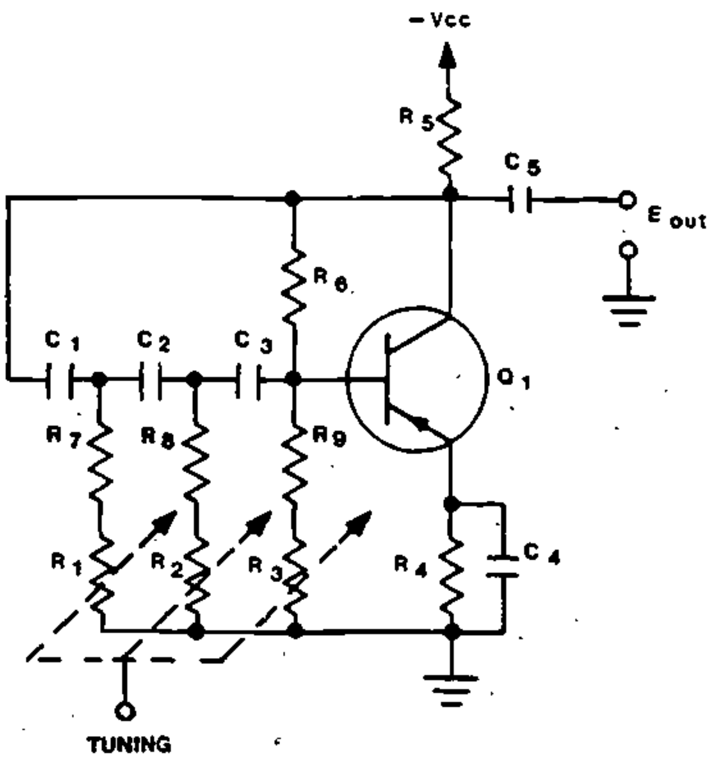


Figure 7

VARIABLE FREQUENCY RC PHASE SHIFT OSCILLATOR

The addition of a ganged variable resistor allows the output frequency to be varied over a limited range. Notice that the ganged variable resistors are part of the total resistance of the phase shift network.

Another technique sometimes used to vary the oscillator output frequency is to use ganged variable capacitors.

The oscillator circuit shown provides a pure, non-distorted, sinusoidal output waveform. Since there is no LC tank circuit to smooth the sine wave output, the oscillator must be operated in Class A service on the linear operating region for the transistor.

As part of the job program associated with this lesson you will have an opportunity to examine the operation of this type of circuit. You will use the NIDA oscillator trainer to familiarize you with the RC phase shift oscillator circuit.

OVERVIEW
LESSON 3

Wien-Bridge Oscillator

In this lesson you will learn about the Wien-bridge oscillator. You will learn how phase shifting is accomplished in this type of oscillator circuit and learn why this type of oscillator is used in test equipment and signal generators. You will also learn how the various components function within the oscillator and how this type of oscillator provides a pure sine wave output with excellent frequency and amplitude stability.

The learning objectives of this lesson are as follows:

TERMINAL OBJECTIVE(S):

32.3.58 When the student completes this lesson, (s)he will be able to IDENTIFY the schematic diagrams, component functions, and operational principles of various Wien-bridge oscillator circuits, including the accomplishment of phase shift, regenerative and degenerative feedback, frequency variation, and automatic gain control. 100% accuracy is required.

ENABLING OBJECTIVES:

When the student completes this lesson (s)he will be able to:

32.3.58.1 IDENTIFY the advantageous characteristics of, and typical applications for, a Wien-bridge oscillator by selecting the correct statement from a choice of four. 100% accuracy is required.

32.3.58.2 IDENTIFY the sections of a Wien-bridge oscillator which accomplish phase shift and frequency selection by selecting the correct statement from a choice of four. 100% accuracy is required.

32.3.58.3 IDENTIFY the components of a Wien bridge which provide degenerative and regenerative feedback by selecting the correct statement from a choice of four. 100% accuracy is required.

32.3.58.4 IDENTIFY the relative amplitudes of the two outputs of a Wien bridge at various frequencies, given a schematic diagram showing the sizes of components, by selecting the correct statement from a choice of four. 100% accuracy is required.

32.3.58.5 IDENTIFY the methods by which the frequency of a Wien-bridge oscillator may be changed by selecting the correct statement from a choice of four. 100% accuracy is required.

32.3.58.6 IDENTIFY the function of components and circuit operation of fixed-frequency, variable-frequency and AGC-type Wien-bridge oscillator circuits, given a schematic diagram, by selecting the correct statement from a choice of four. 100% accuracy is required.

BEFORE YOU START THIS LESSON, READ THE LESSON LEARNING OBJECTIVES AND PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

BASIC ELECTRICITY AND ELECTRONICS

MODULE THIRTY TWO

LESSON 3

WIEN-BRIDGE OSCILLATOR

JULY 1980

SUMMARY
LESSON 3

Wien-Bridge Oscillator

In your previous study of oscillators you learned how the Hartley oscillator and the RC Phase shift oscillator accomplished 360° of phase shift. Remember that this phase shift is necessary in order to provide regenerative feedback to initiate and sustain oscillation.

The Wien-bridge oscillator also requires 360° of phase shifting. With the Wien-bridge oscillator, the phase shift is provided by two amplifiers. Each amplifier accomplishes 180° of phase shift.

The bridge portion of the oscillator determines the output frequency and maintains a constant output amplitude. Figure 1 shows the schematic of the bridge circuit together with block diagrams for the two amplifiers which make up the remainder of the Wien bridge circuit.

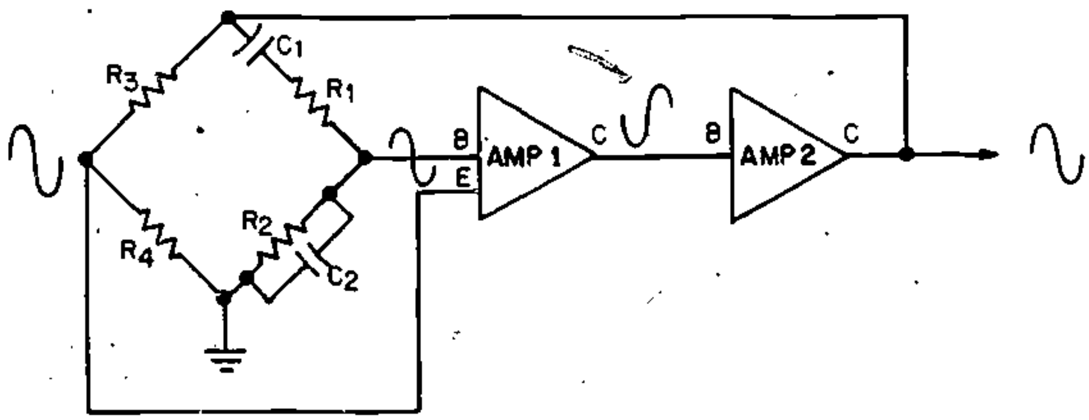


Figure 1

WIEN-BRIDGE OSCILLATOR BLOCK DIAGRAM

Frequency selection in the Wien-bridge oscillator is the result of the resistive-reactive bridge circuit comprised of capacitors C_1 and C_2 and R_1 and R_2. The output of this circuitry is a single frequency, with zero degree phase shift and maximum amplitude. All other frequencies are effectively eliminated. The regenerative output from the bridge circuit is applied to the base of the transistor in the first stage of amplification.

LIST OF STUDY RESOURCES
LESSON 2

Wien-Bridge Oscillator

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following study resources:

Written Lesson presentation in:

Module Booklet:

Summary
Programmed Instruction
Narrative

Student's Guide

Summary
Progress Check

Additional Material(s):

Audio/Visual Program Thirty Two-3 "Wien-Bridge Oscillator"

Enrichment Material(s):

Electronics Installation and Maintenance Book (EIMB)(Test Methods and Practices), NAVSHIPS 0967-000-0120
Basic Electronics, NAVPERS 10087-C

YOU MAY USE ANY, OR ALL, RESOURCES LISTED ABOVE, INCLUDING THE LEARNING CENTER INSTRUCTOR: HOWEVER, ALL MATERIALS LISTED ARE NOT NECESSARILY REQUIRED TO ACHIEVE LESSON OBJECTIVES. THE PROGRESS CHECK MAY BE TAKEN AT ANY TIME.

for each other. This leaves only the resistance of R_1 and R_2. At this frequency, the circuit is purely resistive, no phase shift occurs, with the result that the output voltage is at maximum and is greater than the degenerative voltage.

Refer to the right hand side of Figure 2 and notice that when the output frequency is at the oscillator frequency, the regenerative voltage is greater than the degenerative voltage. Notice also that the degenerative voltage is shown by the dotted line. When the circuit operates at Fo, a maximum regenerative feedback voltage is provided. Because this feedback is greater than the degenerative feed.ack, oscillation occurs and is sustained. At frequencies above the oscillator frequency (Fo), the reactance values are reduced and C_2 becomes the controlling reactance. Recall that in a parallel circuit, the smaller resistance or reactance controls the circuit. Therefore, since the reactance of C_2 controls the parallel combination of R_2-C_2, this causes the output voltage to be less than that at the frequency of operation.

The drawing shown in Figure 3 shows a redrawn version of the Wien bridge circuit together with block diagrams for the two amplifiers which are part of the total circuit.

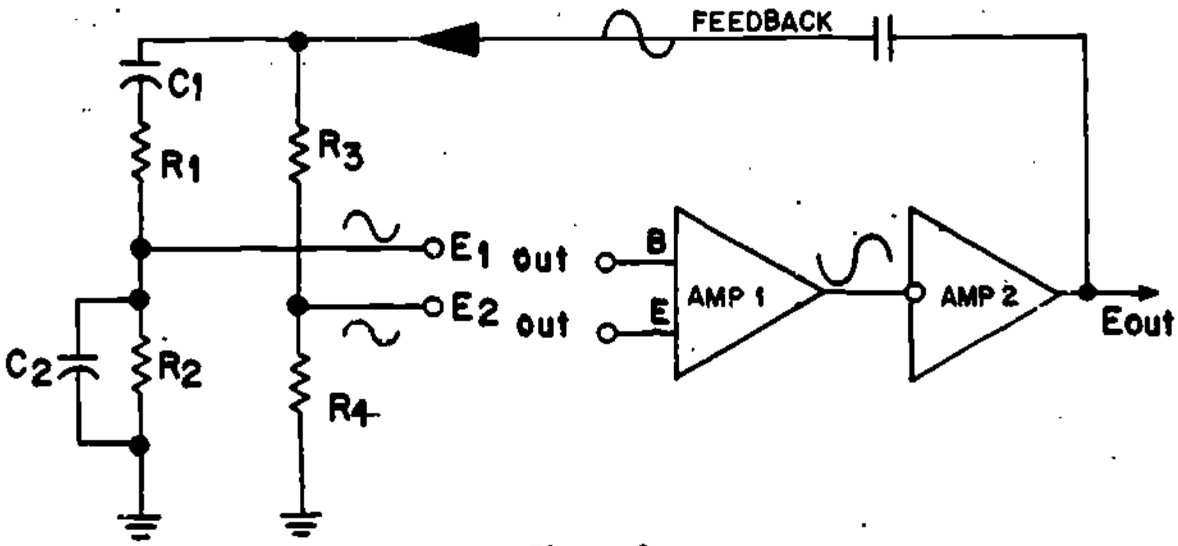


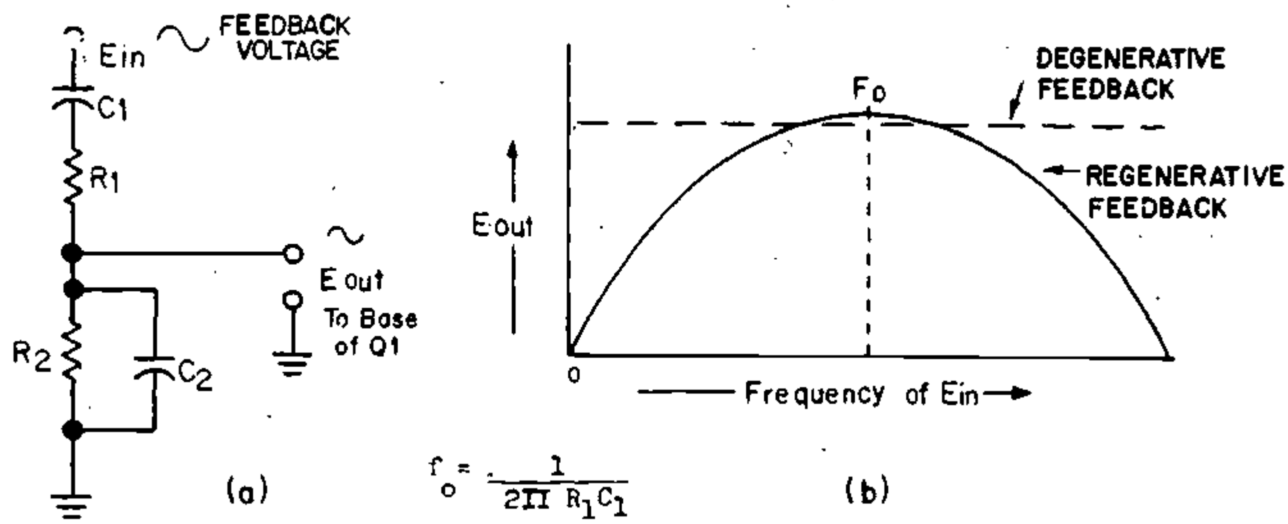
Figure 3

WIEN-BRIDGE OSCILLATOR

The two outputs of the bridge circuit are identified as E_1 out and E_2 out. E_1 is the output from the frequency determining section of the bridge circuit and this regenerative output is applied to the base of the first amplifier. E_2 is the output from the voltage divider, is degenerative, and applied to the emitter of the first amplifier stage.

The remaining components of the bridge circuit, namely, R_3 and R_4 form a voltage divider which provides a degenerative voltage. The output of this circuit is applied to the emitter of the transistor in the first amplifier. Because this voltage is applied to the emitter it opposes the regenerative voltage applied to the transistor's base. Circuit oscillation occurs only when the regenerative feedback voltage exceeds the degenerative feedback voltage. The out-of-phase degenerative feedback voltage acts to regulate the amplitude of the output voltage and improves the purity of the output waveform. Changes in the amplitude of the output signal are automatically compensated for by the degenerative portion of the bridge ciruit. This is necessary to maintain the output amplitude at a constant level.

Figure 2 shows the schematic for the frequency determining network of the Wien-bridge oscillator together with a drawing which shows the relationship of the output voltage amplitude to the frequency of oscillator operation.



$$f_o = \frac{1}{2\pi R_1 C_1}$$

Figure 2

FREQUENCY DETERMINING NETWORK

The frequency of the oscillator is determined by the formula $1 \div 2\pi R_1 C_1$, where $R_1 = R_2$ and $C_1 = C_2$. In this example, and in many Wien-bridge oscillators, R_1 and R_2 are equal value resistors and C_1 and C_2 are equal value capacitors. The output frequency of the oscillator may be changed by increasing or decreasing the resistance or capacitance of R or C in the frequency determining portion of the bridge. At frequencies below the oscillator frequency, the output amplitude of the RC network is less than the output amplitude at the frequency of operation. This is due to the high reactance of C1. At one frequency the reactance of C_1 and C_2 compensate

In the Wien-bridge oscillator circuit automatic gain control (AGC) is used in order to maintain the output amplitude stability. This is shown in Figure 5.

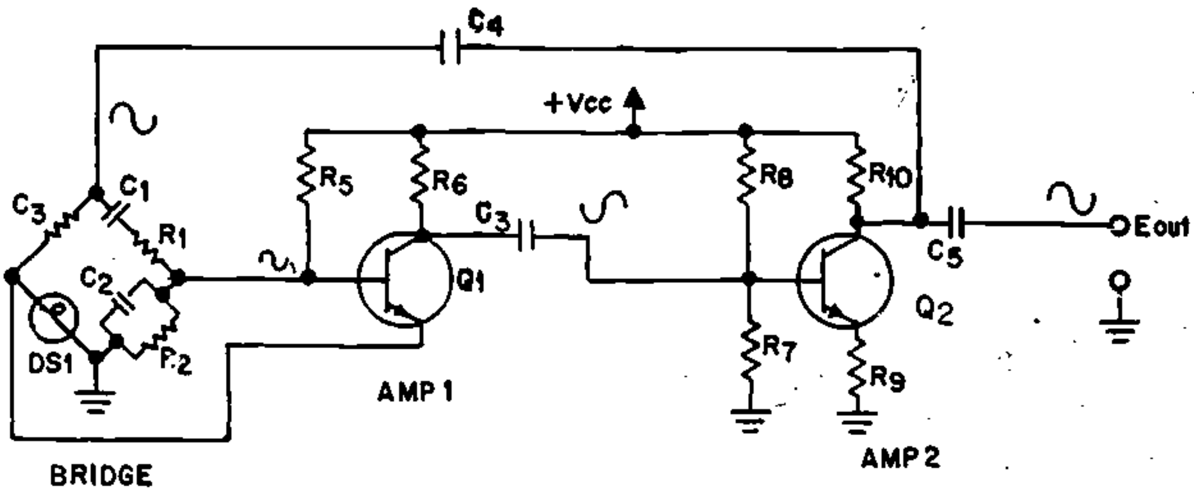


Figure 5

WIEN-BRIDGE OSCILLATOR CIRCUIT WITH AGC

The control is accomplished by substituting a tungsten filament lamp for R_4 in the degenerative voltage divider circuit part of the bridge. This is shown in the schematic. The lamp is designated as DS1. The resistance of the lamp varies as the temperature of its filament increases or decreases. Any increase in the resistance of R_4 (DS1) results in a higher degenerative feedback voltage, whereas any decrease in the resistance results in a smaller degenerative voltage. The tungsten lamp operates much like an AC voltage regulator and maintains a constant output amplitude by varying the amount of degenerative voltage applied to the emitter of transistor Q_1. A thermistor may be used instead of the lamp. This device is also temperature sensitive and functions like the lamp. Thermistors are available with either positive or negative temperature coefficients. The circuit application will determine the type of thermistor which is required. With the Wien-bridge oscillator, a thermistor with a positive temperature coefficient is required.

The schematic shown in Figure 4 is that of a complete Wien bridge circuit.

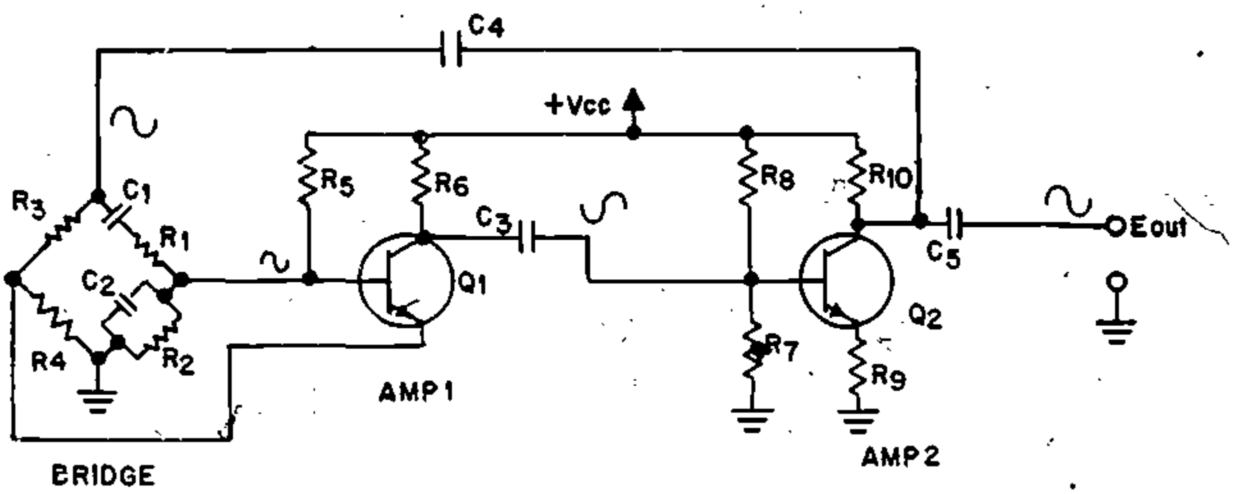


Figure 4

WIEN-BRIDGE OSCILLATOR

In addition to the bridge circuit, the two amplifier circuits which accomplish the 360° phase shift are shown. Notice that waveforms are also indicated on the schematic. Both of the amplifiers in this circuit are biased to operate in Class A service. Recall that this class of operation causes the transistor to conduct during the entire input cycle and produces a distortion-free output. Notice particularly that the regenerative feedback is connected to the base of Q_1 and the degenerative feedback is connected to the emitter of the transistor. Recall also that the degenerative feedback opposes the regenerative feedback applied to the transistor's base.

The function of the amplifier stage components is as follows: Foward bias for transistor Q_1 is provided by voltage divider R2/R5, while R7/R8 perform the same function for Q_2. R6 and R10 act as collector load resistors while R4 and R9 are emitter resistors for Q_1 and Q_2 respectively. C3 functions as the inter-stage coupling capacitor and C5 is the output coupling capacitor. C4 is the feedback capacitor which couples a portion of the output signal back to the bridge circuit.

PROGRAMMED INSTRUCTION
LESSON 3

Wien-Bridge Oscillator

TEST FRAMES ARE 4, 11, AND 17. PROCEED TO TEST FRAME 4, AND SEE IF YOU CAN ANSWER THE QUESTIONS. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

1. In Lessons 1 and 2 of this module you learned how the Hartley oscillator and RC phase shift oscillator accomplish 360° of phase shift. The drawings in Figure 1 show the amount of phase shift contributed by each section of these oscillators.

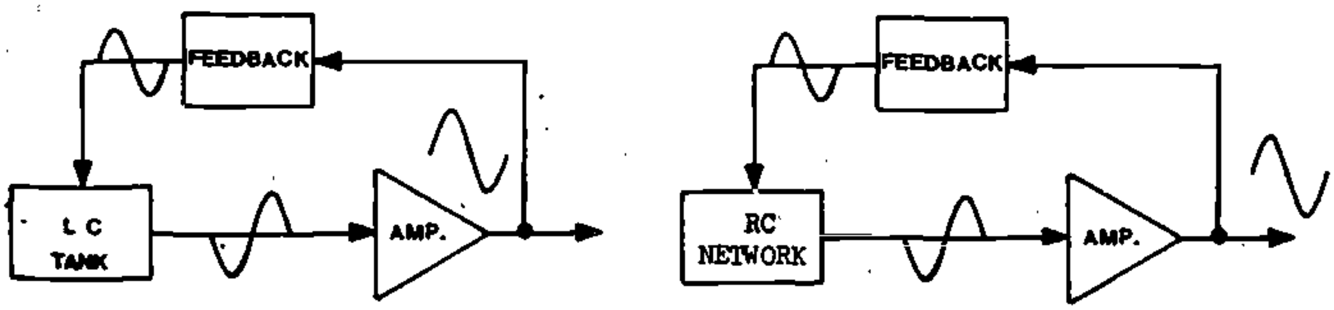


Figure 1

PHASE SHIFTING

Remember that unless the phase shift is complete, or 360°, the regenerative feedback will not initiate or sustain oscillation. If you do not recall how the Hartley oscillator or the RC phase shift oscillator accomplishes the 360° phase shift, please refer back to Lessons 1 and 2 of this module.

Since the output frequency of the Wien-bridge oscillator may be changed by changing the values of C_1 and C_2, it is possible to have a variable frequency Wien-bridge oscillator. The schematic for such an oscillator is shown in Figure 6.

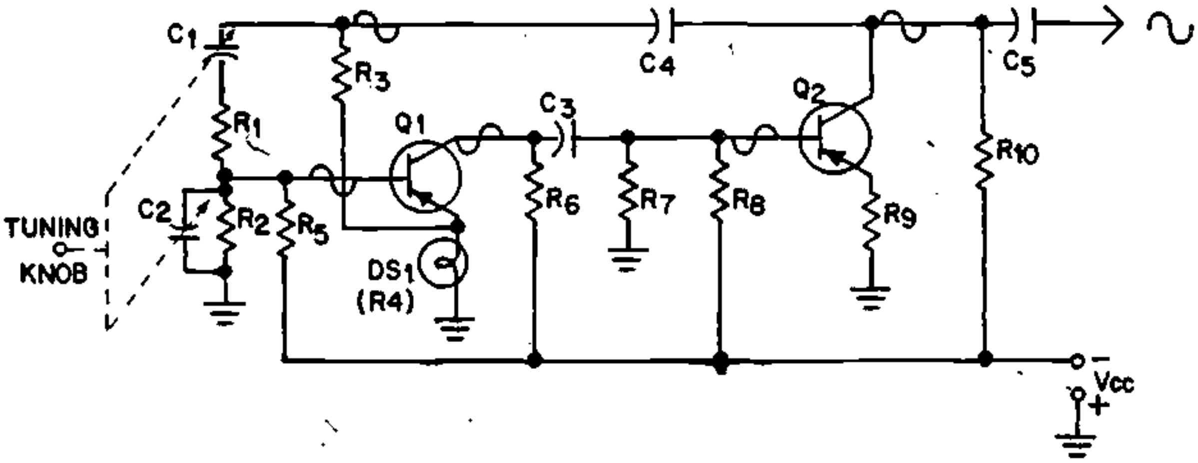


Figure 6

VARIABLE FREQUENCY WIEN-BRIOGE OSCILLATOR

Notice that the circuit shown in Figure 6 is similar to the circuit shown in Figure 5 except C_1 and C_2 are ganged and variable which allows the output frequency of the oscillator to be varied. When variable capacitors are used in the Wien bridge circuit the frequency may be varied from several Hz to over 200 kHz. Again refer to the schematic shown in Figure 6 and notice that PNP transistors may be used. Notice also the waveforms which have been superimposed on the schematic to help you understand the operation of the Wien-bridge oscillator circuit.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, YOU MAY TAKE THE LESSON TEST. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUOY THE PARTS OF THIS LESSON YOU ARE HAVING OIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH LEARNING CENTER INSTRUCTOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

Each of the amplifiers in the Wien-bridge oscillator circuit provides
__________ degrees of phase shift.

a. 360

b. 270

c. 180

d. 90

---

c. 180

(3.) The components which determine the output frequency of a Wien-bridge oscillator are shown in the dotted region with block diagrams for the two amplifiers which form the remainder of the oscillator circuit in Figure 3.

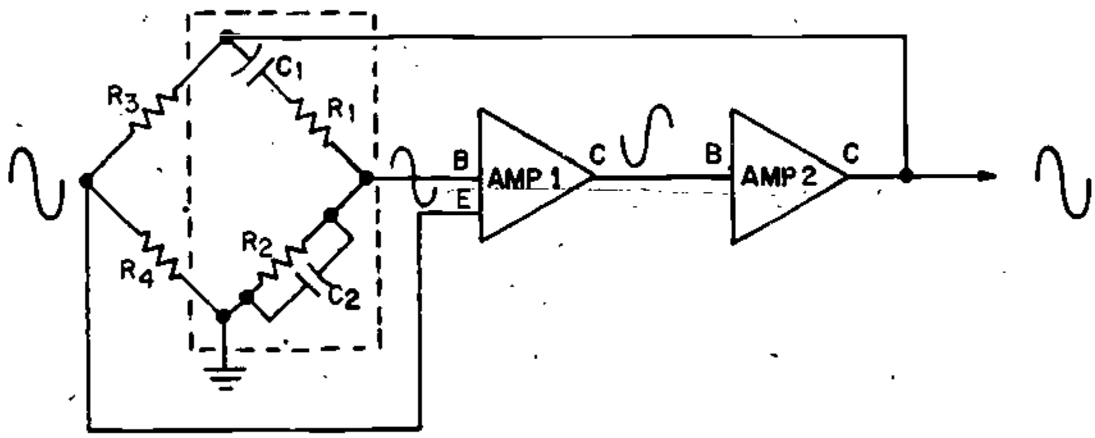


Figure 3

WIEN-BRIDGE OSCILLATOR

In order to initiate and sustain oscillation, an oscillator must provide

__________ degrees of phase shift.

a. 60

b. 180

c. 270

d. 360

---

d. 360

(2.) The Wien-bridge oscillator provides a sinusoidal output with excellent frequency stability and a constant output amplitude. This oscillator is used most frequently with test and laboratory equipment. To accomplish the necessary 360° phase shift, the oscillator uses two amplifiers. This is illustrated pictorially in Figure 2.

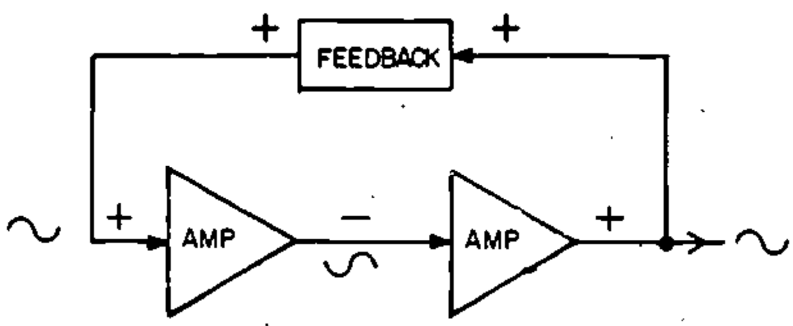
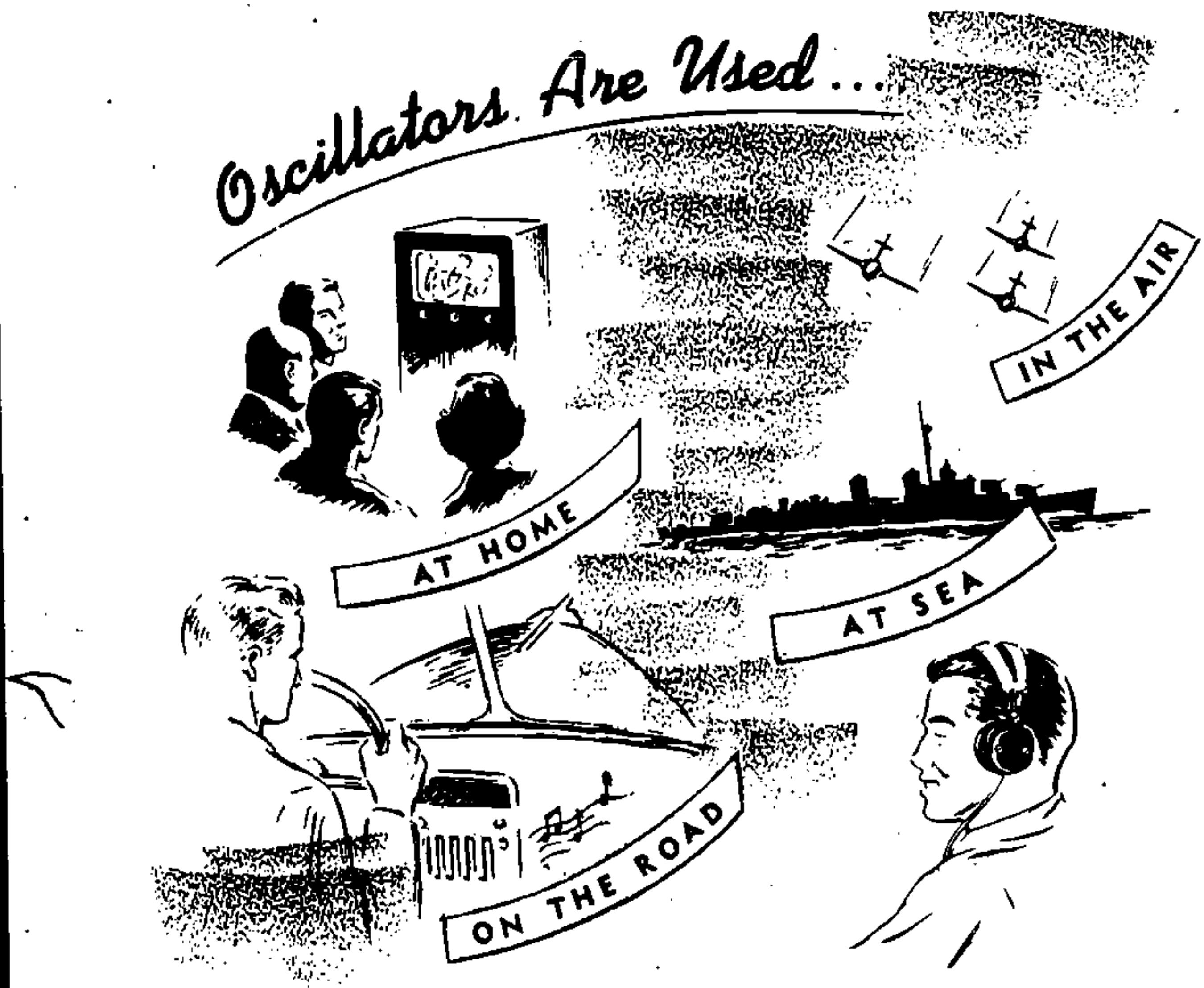


Figure 2

WIEN BRIDGE PHASE SHIFTING

Notice that each of the amplifiers provides 180° of phase shift, thus the regenerative feedback, which is necessary to sustain oscillation is shifted a full 360° and is in phase with the input.


Oscillators Are Used . . .
AT HOME
IN THE AIR
AT SEA
ON THE ROAD

The frequency selection portion of the circuit is made up of C1, C2, R1, and R2. This oscillator uses a resistive-reactive bridge circuit to select the oscillator frequency. This will be explained in greater detail in subsequent frames.

The primary purpose of the resistive-reactive bridge circuit in the Wien-bridge oscillator is to

a. provide regenerative feedback

b. provide degenerative feedback

c. determine oscillator frequency

d. filter the circuit output

---

c. determine oscillator frequency

1. c. amplifier
2. d. 360°
3. a. bridge

IF YOUR ANSWERS MATCH THE CORRECT ANSWERS YOU MAY GO TO TEST FRAME 11 OTHERWISE GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE AGAIN BEFORE TAKING TEST FRAME 4 AGAIN.

5. The schematic diagram shown in Figure 4 is that portion of the Wien-bridge oscillator circuit which determines the output frequency and also provides degenerative feedhack to maintain a constant output amplitude.

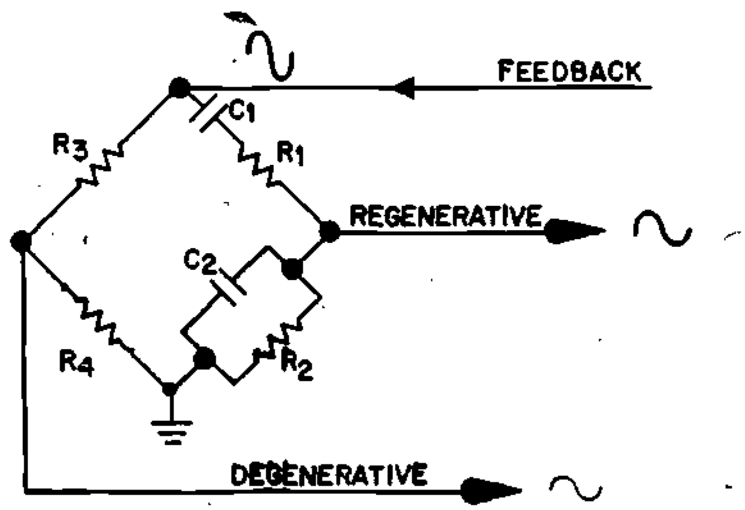


Figure 4

WIEN BRIDGE COMPONENTS

The resistive capacitive voltage divider of the bridge circuit consisting of R1, C1, R2 and C2 determines the output frequency of the oscillator. In this example, and most Wien-Bridge oscillators, R1 and R2 and C1 and C2 are of equal value.

Resistors R3 and R4 form a resistive voltage divider to provide an out-of-phase degenerative feedback voltage.

4. THIS IS A TEST FRAME. COMPLETE THE TEST QUESTIONS AND COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE PAGE FOLLOWING THE QUESTIONS.

1. A Wien-bridge oscillator accomplishes the necessary phase shift with
   a. RC networks
   b. tank circuits
   c. amplifiers
   d. rectifiers
2. A phase shift of ________ degrees is necessary to initiate and to sustain oscillation.
   a. 90
   b. 180
   c. 270
   d. 360
3. The output frequency of a Wien-bridge oscillator is determined by the ________ circuit.
   a. bridge
   b. amplifier
   c. rectifier
   d. decoupling

The output frequency may be increased by decreasing the resistance or capacitance. Increasing the resistance or capacitance results in a decrease in the output frequency of the oscillator.

The output frequency of a Wien-bridge oscillator may be increased by __________ the resistance or capacitance of the bridge circuit.

a. increasing

b. decreasing

---

b. decreasing

7. The degenerative feedback of the Wien-bridge oscillator circuit is provided by the resistive voltage divider consisting of resistors R_3 and R_4. This is shown in Figure 6.

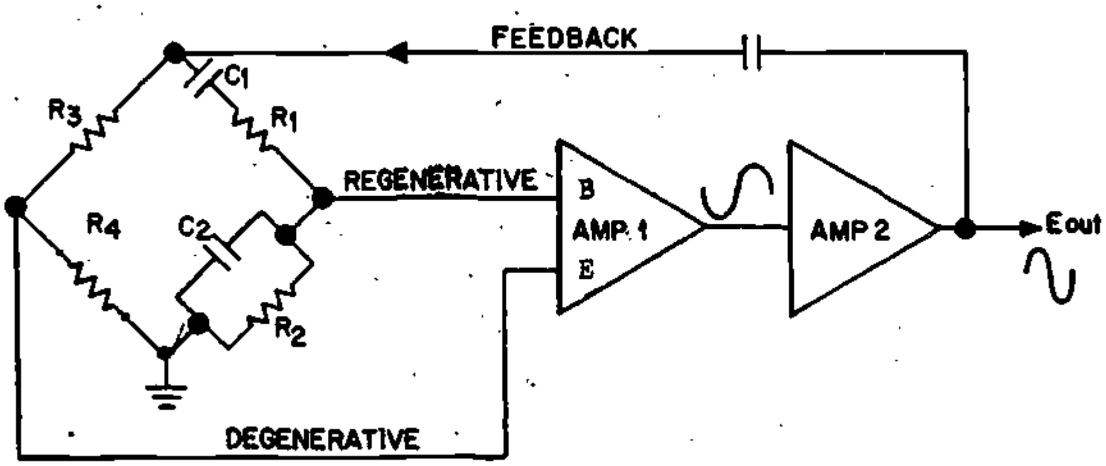


Figure 6

DEGENERATIVE FEEDBACK NETWORK

A Wien-bridge oscillator uses a __________ circuit to accomplish frequency selection.

a. transformer

b. LC tank

c. resistive-capacitive bridge

d. inductive-capacitive bridge

---

c. resistive-capacitive bridge

6. The schematic shown in Figure 5 is the portion of the bridge section of the oscillator circuit which determines oscillator frequency.

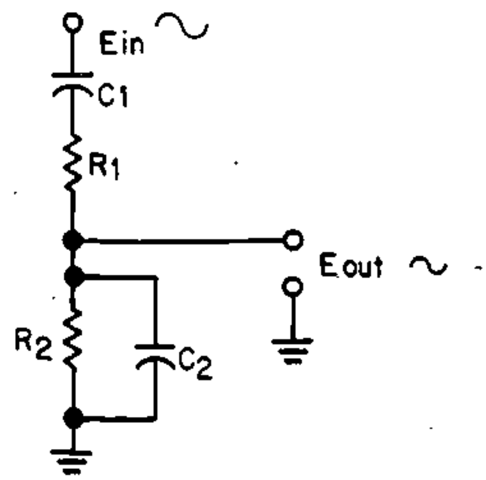


Figure 5

FREQUENCY DETERMINING NETWORK

The frequency of the Wien-bridge oscillator is determined by the formula $Fo = \frac{1}{2\pi RC}$, where R and C are the components in the series or parallel leg of the bridge (usually R1 equals R2 and C1 equals C2).

8. Figure 7 shows the frequency determining components of the Wien-bridge oscillator, an equivalent RC network and a diagram which shows the relationship of the output voltage compared with the output frequency below Fo.

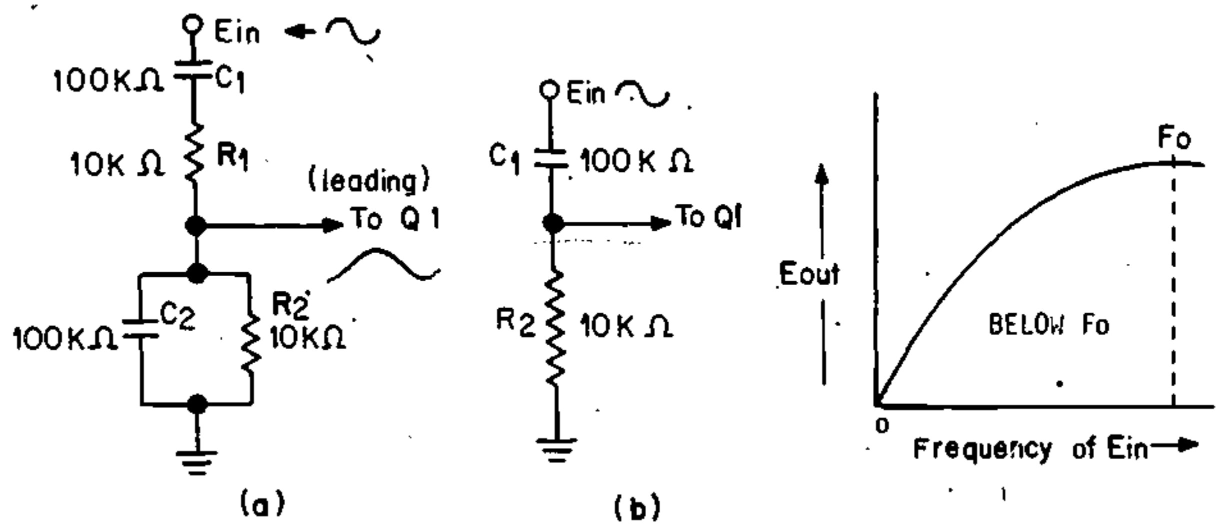


Figure 7

EQUIVALENT CIRCUIT BELOW Fo

The action of the RC frequency determining components will now be explained. These components act in a manner which provides one output frequency that has a maximum amplitude and zero degrees of phase shift. Let's see how this is accomplished.

At frequencies below the oscillator Fo, the output from the RC network will be less than maximum with a leading phase angle. This is primarily due to the high reactance of CI and can be understood by noting the approximate values on the diagram. Notice in 7(a) that the reactance of CI becomes larger than the resistance of RI. This makes the R-C circuit appear like the equivalent of Figure 7(b), where most of the voltage is dropped across CI.

This divider forms part of the bridge circuit and its output provides the input voltage to the emitter of the transistor in the first amplifier. Since this voltgage is applied to the emitter it opposes the voltage applied to the transistors base.

Oscillation occurs in this circuit only when the regenerative feedback voltage exceeds the degenerative feedback voltage. The out-of-phase degenerative feedback voltage acts to regulate the amplitude of the output voltage and improve the purity of the waveform. Any change in the amplitude of the output signal will be automatically compensated for by the degenerative portion of the bridge in a manner that will help to maintain output amplitude constant.

Degenerative feedback acts to ___________ the output amplitude.

a. regulate

b. dissipate

c. amplify

d. increase

---

a. regulate

At frequencies above Fo, the output voltage is less than maximum because of the low reactance of capacitor ________.

a. C1

b. C2

B. C2

(10.) The schematic for the frequency determining portion of the bridge circuit, the equivalent RC circuit, and a diagram showing the relationship of voltage output and oscillator frequency at Fo is shown in Figure 9.

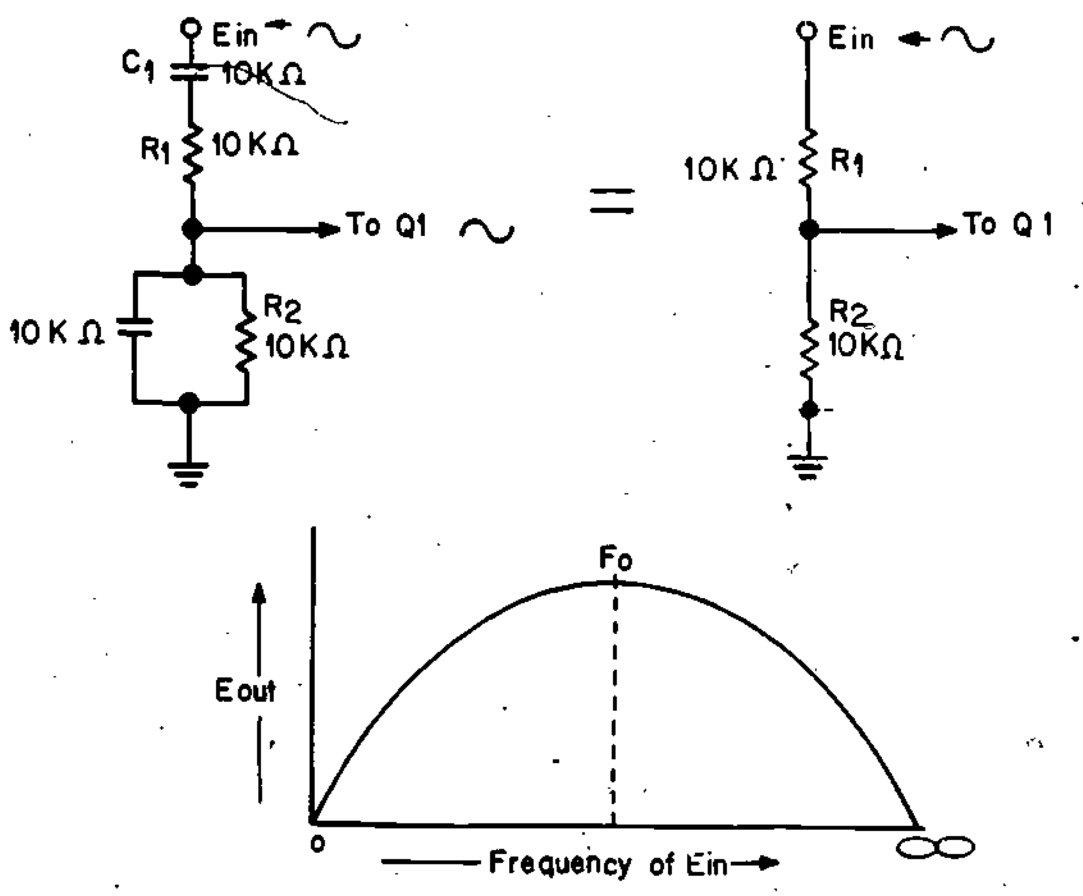


Figure 9

EQUIVALENT CIRCUIT-Fo

At frequencies below the oscillator frequency, the output voltage of the RC network is ________ (less than/greater than) the output voltage at Fo.

---

less than

(9.) Figure 8 shows the frequency determining bridge circuit together with the equivalent RC circuit for frequencies above the operating frequency of the oscillator.

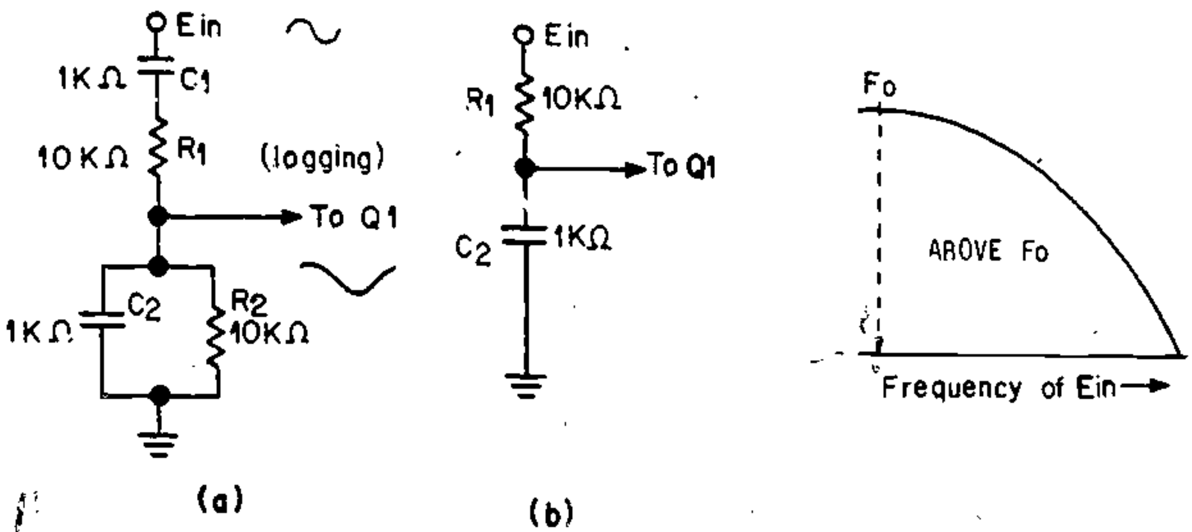


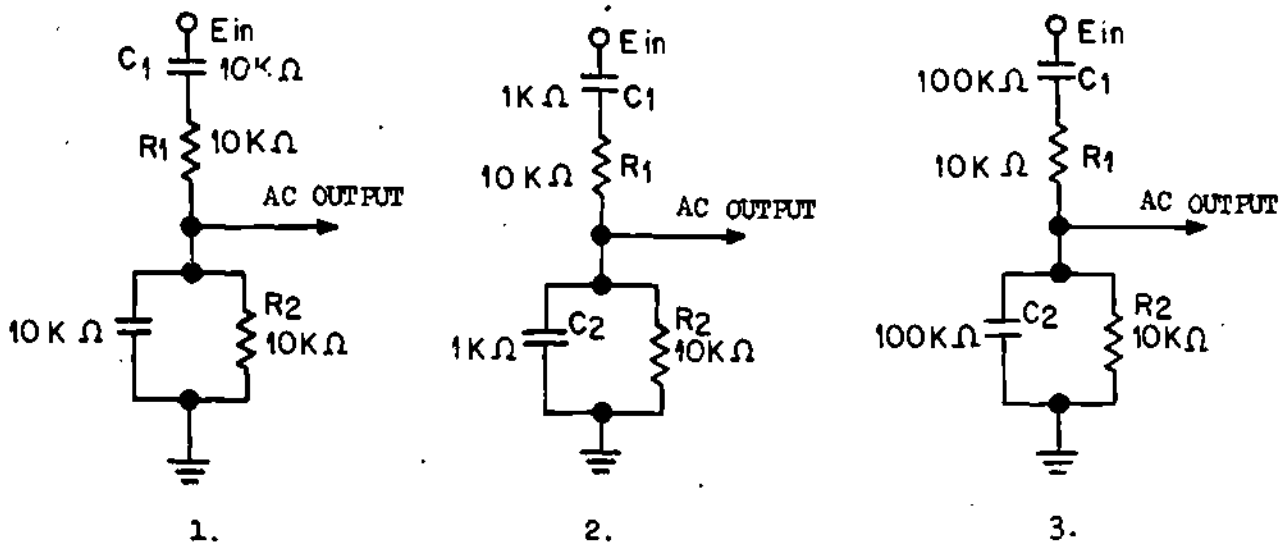
Figure 8

EQUIVALENT CIRCUIT ABOVE Fo

Now let's examine the RC network at frequencies above the oscillator frequency of Fo. The values of the reactance are considerably reduced at these higher frequencies, and capacitor C2 becomes the controlling reactance. Remember that in a parallel circuit, the smallest resistance or reactance controls the circuit. Hence the reactance of C2 controls the parallel combination of R2-C2 and causes the output voltage to become less than that at Fo with a lagging phase angle.

11. THIS IS A TEST FRAME. ANSWER THE TEST QUESTIONS AND COMPARE YOUR ANSWERS WITH THE ANSWERS GIVEN AT THE TOP OF THE PAGE FOLLOWING THE TEST QUESTIONS.

REFER TO THE SCHEMATIC DIAGRAMS SHOWN BELOW WHEN ANSWERING QUESTIONS 1, AND 2.



1. The circuit which provides maximum AC voltage output is

   a. one

   b. two

   c. three

2. Which circuits will provide an output voltage which is less than the voltage at Fo?

   a. one-two

   b. two-three

   c. one-three

At Fo, the reactance of C1 and C2 compensate for each other, leaving only the resistance of R1 and R2. Since this equivalent circuit is purely resistive, no phase shift occurs. The output voltage is maximum at this time and greater than the degenerative voltage output from the other leg of the bridge. Since the circuit is operating at Fo, a maximum regenerative feedback voltage is provided. Since this feedback is greater than the degenerative feedback, oscillation occurs and is sustained.

Study the diagram on the bottom of Figure 9 in order to answer the following question.

Maximum feedback voltage is achieved ___________.

a. below output frequency

b. above output frequency

c. at the oscillator's output frequency

---

c. at the oscillator's output frequency

125

1. a. one
2. b. two-three
3. b. decreasing

IF YOUR ANSWERS MATCH THE CORRECT ANSWERS YOU MAY GO TO TEST FRAME 17 OTHERWISE, GO BACK TO FRAME 5 AND TAKE THE PROGRAMMED SEQUENCE AGAIN BEFORE TAKING TEST FRAME 11 AGAIN.

12. The drawing shown in Figure 10 is a re-drawn Wien bridge circuit, together with block diagrams for the two amplifiers which are part of the total circuit.

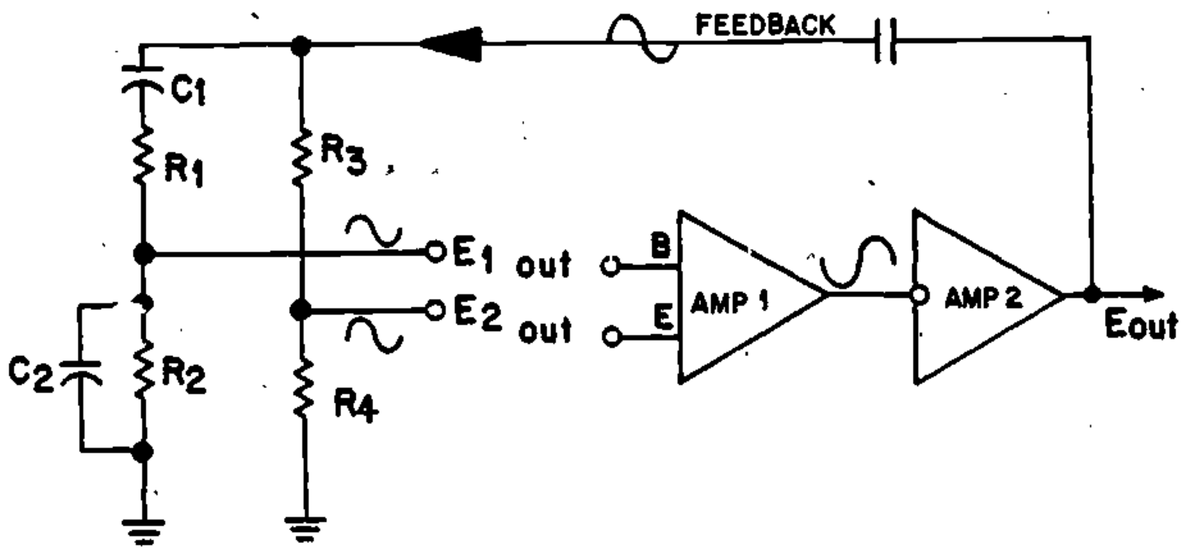


Figure 10

WIEN-BRIDGE OSCILLATOR

3. The output frequency of the oscillator may be increased by ________ the value of the resistors or capacitors in the bridge circuit.

a. increasing

b. decreasing

127

(13.) The drawing shown in Figure 11 shows the relationships of the regenerative and degenerative feedbacks to the output frequency (Fo).

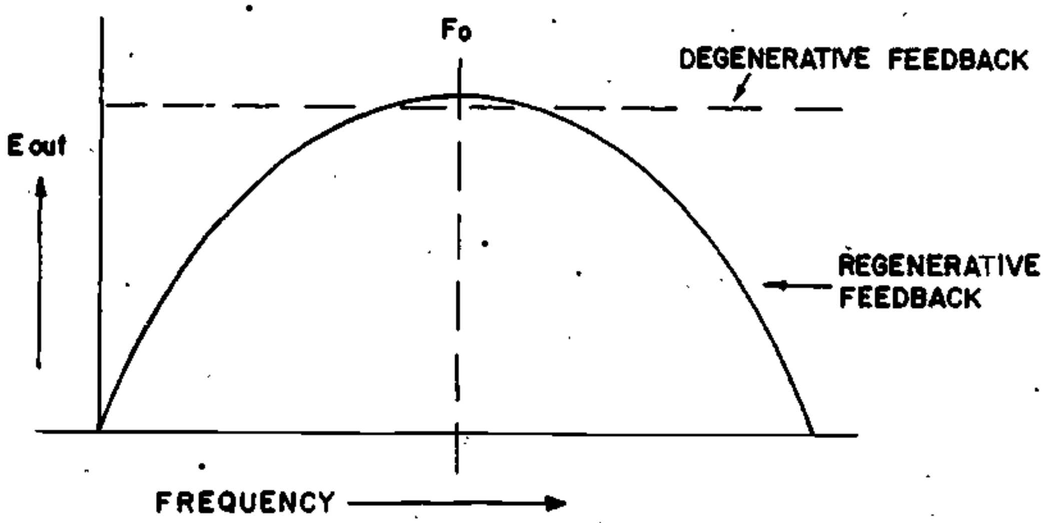


Figure II

FEEDBACK VOLTAGE OUTPUT RELATIONSHIP

Degenerative feedback is shown with a broken horizontal line. This voltage is constant and is not frequency sensitive like the regenerative feedback. The regenerative feedback is shown with a solid line.

Recall that the amount of degenerative feedback is determined by the action of the resistive voltage divider made up of R3 and R4. This degenerative voltage may be changed by changing the ratio of R3 and R4. The degenerative feedback voltage may be increased by increasing the resistance of R4 or decreasing the resistance of R3.

Notice that two outputs from the bridge are shown identified as E1 and E2 out. E1 is the output from the frequency determining portion of the bridge circuit, is regenerative and is applied to the base of the first amplifier. E2 is the output from the voltage divider, is degenerative, and is applied to the emitter of the first amplifier stage.

The output of the frequency determining network (E1 out) is regenerative feedback necessary to sustain oscillation. The output of the voltage divider (E2 out) is degenerative and opposes the input signal to the amplifier. This feedback ensures amplitude stability. Both types of feedback are necessary in order for oscillation to occur at the selected frequency.

The Wien bridge uses both _________ and _________ type of feedback in order to oscillate properly and insure that oscillations occur only at the selected output frequency.

---

regenerative, degenerative

(14.) Figure 12 shows the schematic for a complete Wien-bridge oscillator circuit. Besides the bridge circuit the two amplifier circuits which effect the 360° phase shift are shown (inside dotted lines).

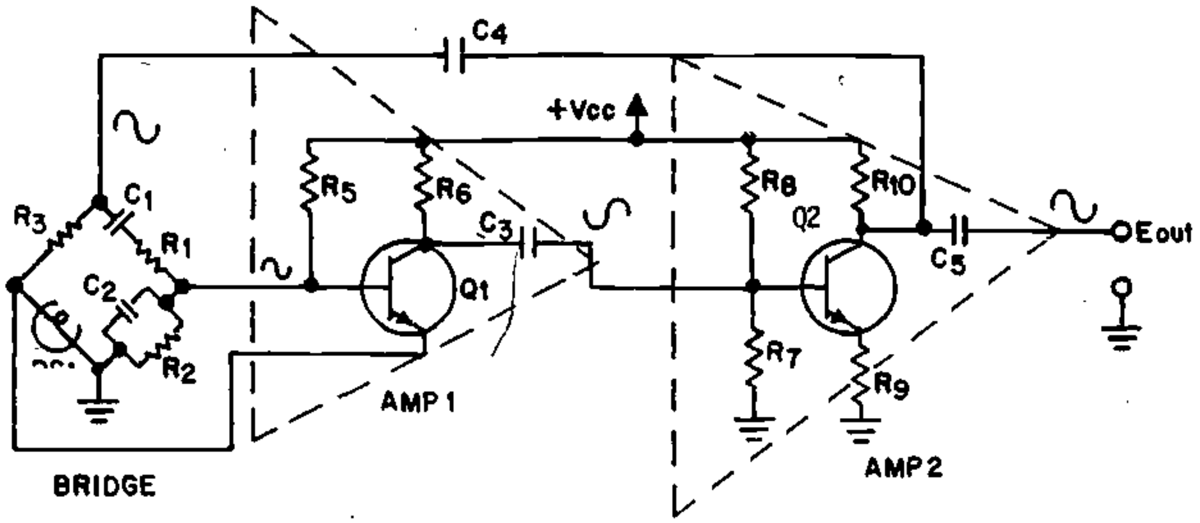


Figure 12

WIEN-BRIDGE OSCILLATOR

Both of the amplifiers are biased to operate in class A service. Remember that this class of operation causes the transistor to conduct during the entire input cycle and produces a distortion free output. Notice also that the regenerative feedback is connected to the base of Q1 and the degenerative feedback is connected to the emitter of Q1. Remember that this feedback opposes the regenerative feedback applied to the base of Q1.

In a Wien bridge circuit the ____________ feedback is connected to the base of transistor Q1 and the ____________ feedback is connected to the emitter.

a. degenerative, regenerative

b. regenerative, degenerative

---

b. regenerative, degenerative

Refer to the diagram and notice that the degenerative feedback voltage exceeds the regenerative voltage at all times except when the regenerative feedback is in phase with the oscillator's output frequency. At this time oscillation occurs. Whenever degenerative feedback exceeds regenerative feedback, oscillation ceases.

Oscillation occurs when the regenerative feedback is ________________ the degenerative feedback.

a. greater than

b. equal to

c. less than

---

a. greater than

positive or negative temperature coefficient. The application determines the type required. The Wien-bridge oscillator circuit requires the use of one with positive temperature coefficient.

When the current through DS1 decreases, the resistance of the lamp

_______________.

a. increases

b. decreases

c. remains constant

---

b. decreases

(16.) The schematic shown in Figure 14 is that of a variable frequency Wien-bridge oscillator. In this case capacitors C1 and C2 are ganged and varying their capacitance results in a variable output frequency.

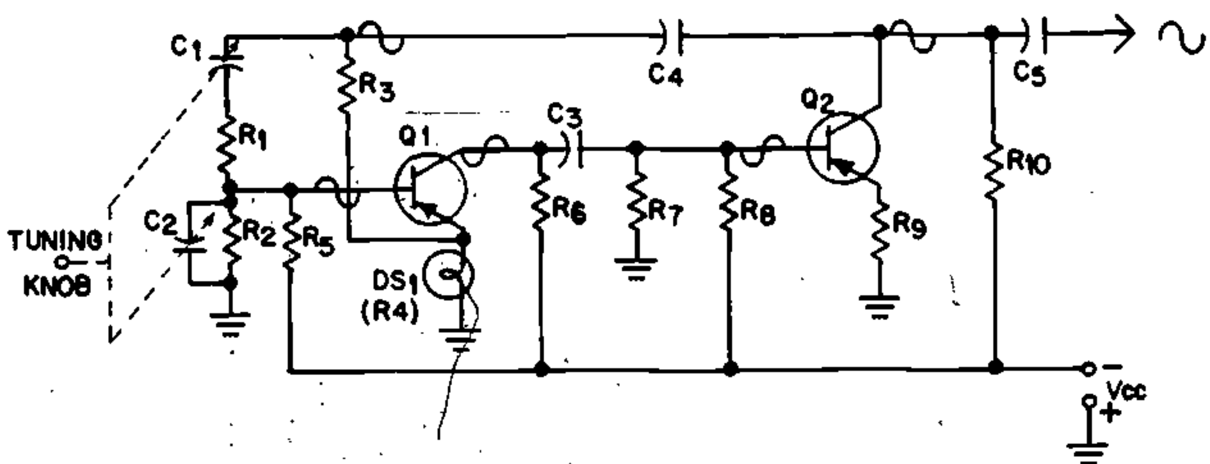


Figure 14

VARIABLE FREQUENCY WIEN-BRIDGE OSCILLATOR

(15.) In order to maintain the output amplitude stability of the Wien-bridge oscillator, Automatic Gain Control (AGC) is used. Control is improved by substituting a tungsten filament lamp for resistor R4 in the voltage divider circuit. This is shown in Figure 13.

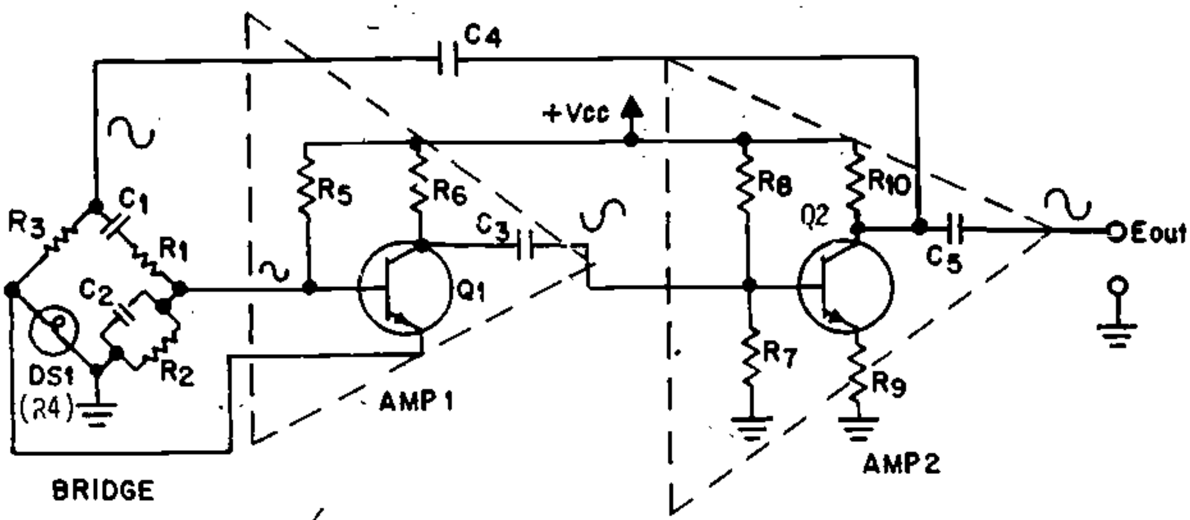


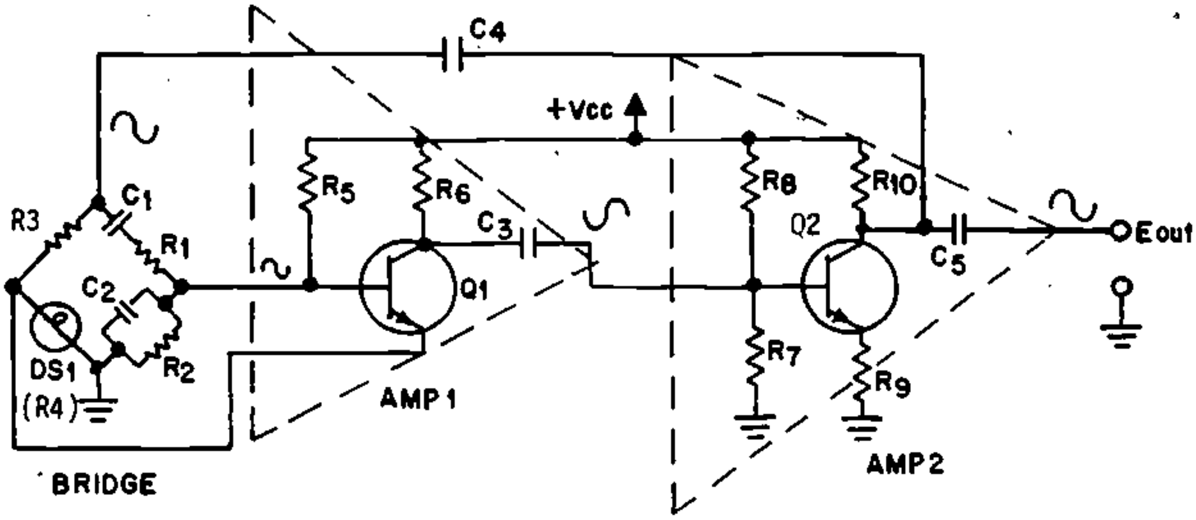
Figure 13

WIEN-BRIDGE OSCILLATOR WITH AGC

The lamp has the property of varying its resistance as its temperature varies. When the temperature increases, the resistance of the lamp also increases. In other words it has a positive temperature coefficient. Any increase in the resistance of R4 (DS1) results in a higher degenerative feedback voltage. This means there is more opposition to the regenerative feedback. A decrease in the resistance of R4 results in a smaller degenerative feedback voltage. In effect the tungsten lamp functions like an AC voltage regulator and maintains a constant output amplitude. The lamp may be replaced with a "thermistor.". This device is also heat sensitive and functions like the lamp. Thermistors are available with either a

17. THIS IS A TEST FRAME. ANSWER THE TEST QUESTIONS AND COMPARE YOUR ANSWERS WITH THE ANSWERS GIVEN AT THE TOP OF THE PAGE FOLLOWING THE TEST QUESTIONS.

Refer to the schematic shown below when answering questions 1 through 7.



1. The components which determine the output frequency of the Wien-bridge oscillator shown are

   a. Q1, Q2, and R10

   b. R3 and R4

   c. R3, R4, R6, and Q1

   d. R1, R2, C1, and C2

2. The components, which determine the amount of degenerative feedback are

   a. R1 and R2.

   b. R3 and R4 (DS1).

   c. R3 and R5.

   d. R4(DS1) and R6.

By using variable capacitors, the oscillators frequency may be varied from several Hz to over 200 kHz.

Refer again to the schematic and notice that PNP transistors may also be used. Also notice the waveforms which have been superimposed on the schematic to help you understand the operation of the circuit.

No response required

135

1. d. R1, R2, C1 and C2
2. b. R3 and R4 (DS1)
3. c. DSI (R4)
4. c. 180
5. a. regenerative
6. b. degenerative
7. c. 180 degrees out of phase

IF YOUR ANSWERS MATCH THE CORRECT ANSWERS YOU HAVE COMPLETED THE PROGRAMMED INSTRUCTION FOR LESSON 3, MODULE THIRTY-TWO. OTHERWISE GO BACK TO FRAME 12 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 17 AGAIN.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, YOU MAY TAKE THE LESSON TEST. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH THE LEARNING CENTER INSTRUCTOR UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

3. The component which provides automatic gain control is

   a. Q1

   b. R5

   c. DS1 (R4)

   d. R3

4. Q1 and Q2 each provide ________ degrees of phase shift

   a. 60

   b. 90

   c. 180

   d. 360

5. What type of feedback is felt at the base of Q1?

   a. regenerative

   b. degenerative

   c. in phase

   d. superfluous

6. The feedback at the emitter of Q1 is

   a. regenerative

   b. degenerative

   c. in phase

   d. superlative

7. The output waveform from the collector of Q1 is _______ with the input waveform

   a. in phase

   b. 90° out-of-phase

   c. 180° out-of-phase

   d. 270° out-of-phase

137

The Wien-bridge oscillator uses a resistive-reactive bridge circuit to select a single oscillator frequency. This circuit, together with block diagrams for the two amplifiers which form the remainder of the oscillator circuit, is shown in Figure 2.

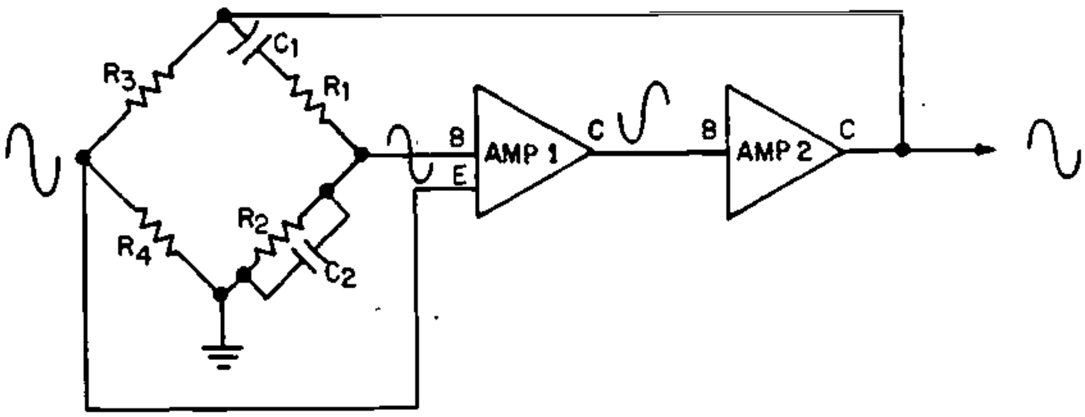


Figure 2

WIEN-BRIDGE OSCILLATOR BLOCK DIAGRAM

The resistive reactive voltage divider of the bridge circuit consisting of R1, C1, and R2, and C2 determines the output frequency of the oscillator. The frequency at which the circuit oscillates is determined by the values of the components used in the RC portion of the bridge. The product of R1 times C1 is equal to R2 times C2. In most Wien-bridge oscillators the resistors and capacitors are of equal value. Therefore, R1 equals R2 and C1 equals C2. The actual operating frequency of the oscillator may be computed by substituting in the formula: $F_o = \frac{1}{2\Pi R_1 C_1}$, $R_1 = R_2$ and $C_1 = C_2$

This is true where R1 equals R2 and C1 equals C2. The frequency of operation may be changed by changing the resistance or capacitor values. The oscillators output frequency may be increased by decreasing the resistance or the capacitance. If the resistance value or capacitance value is increased, this will result in a decrease in the oscillator output frequency.

NARRATIVE
LESSON 3

Wien-Bridge Oscillator

The Wien-bridge oscillator is a variable frequency oscillator that is often used for test equipment and laboratory equipment. This type of oscillator provides a sinusoidal output which has exceptional stability and almost constant output amplitude over the audio frequency and low radio frequency range.

In your previous study of oscillators you learned that a 360° phase shift is necessary to provide regenerative feedback. You also learned that feedback is necessary in order to initiate and sustain oscillation. Recall that the Hartley oscillator used an LC tank to effect 180° of phase shift and that the phase shift oscillator used an RC network to effect 180° of phase shift. In both cases a total 360° phase shift is accomplished. The Wien-bridge oscillator uses two amplifiers to accomplish the 360° phase shift. This is illustrated pictorially in Figure 1.

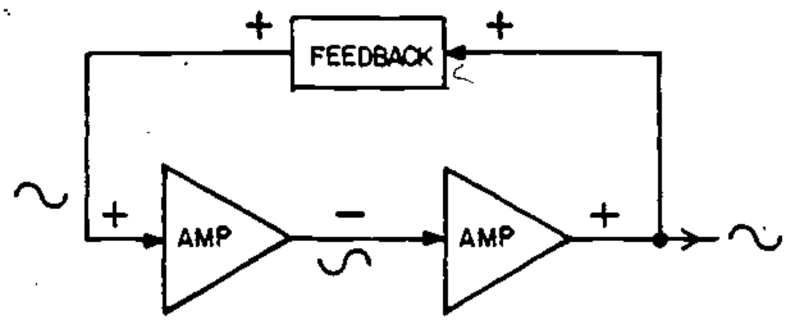


Figure 1

BASIC WIEN BRIDGE FEEDBACK

With the Wien bridge circuit, each of the amplifiers provides 180° of phase shift for a total of 360°. This provides a regenerative feedback which is both necessary to initiate and sustain oscillation and is in phase with the input. However, this principle applies to all frequencies.

139

The frequency selection process action of the voltage divider at frequencies below and above Fo will now be explained. Figure 4 shows the frequency determining network of the Wien-bridge oscillator together with a diagram which shows the relationship of the voltage output and oscillator frequency.

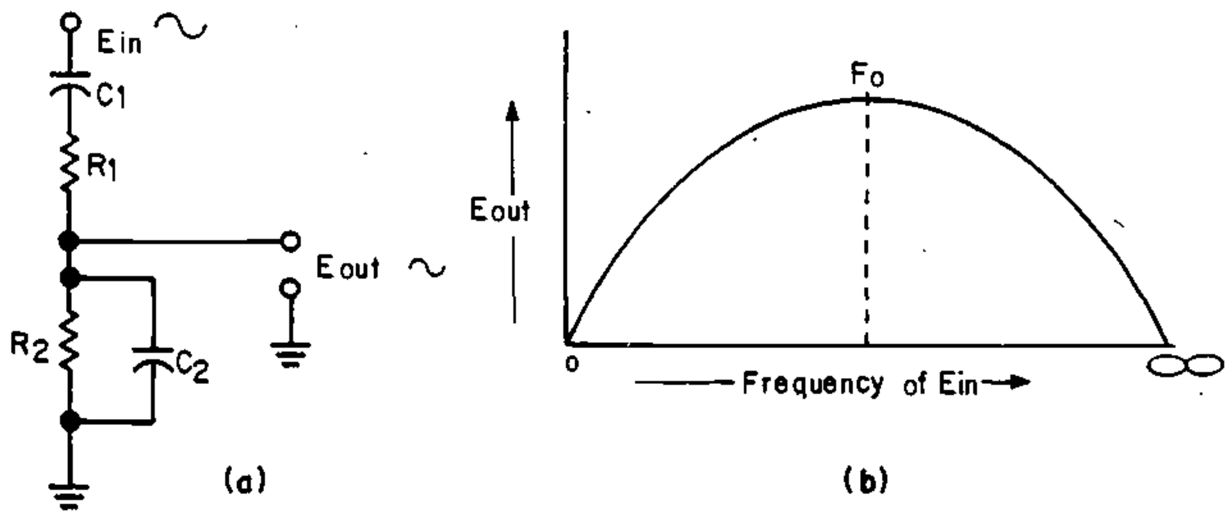


Figure 4

FREQUENCY DETERMINING NETWORK

The RC frequency determining components function to provide one output frequency which has a maximum amplitude with zero degrees phase shift.

Besides determining the output frequency of the oscillator, the bridge circuit provides degenerative feedback to maintain a constant output amplitude. Resistors R3 and R4 form a resistive voltage divider and provide the out-of-phase degenerative feedback. These components are enclosed with broken lines in Figure 3.

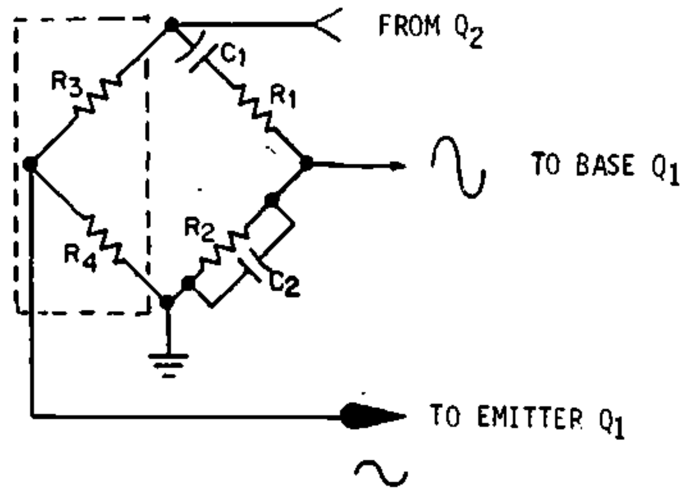


Figure 3.

WIEN BRIDGE CIRCUIT

The output of this divider provides the input voltage to the emitter of the transistor in the first amplifier stage. Because this voltage is applied to the emitter, it opposes the voltage applied to the transistor's base. Oscillation only occurs in this circuit when the regenerative feedback voltage exceeds the degenerative feedback voltage. The out-of-phase degenerative feedback voltage acts to regulate the amplitude of the amplifier output and improve the purity of the waveform. Changes in the amplitude of the output signal are automatically compensated for by the degenerative portion of the bridge circuit in such a way that the output remains constant.

141

The diagram drawing shown in Figure 6 is a redrawn Wien-bridge circuit, together with block diagrams for the two amplifiers which are part of the total circuit.

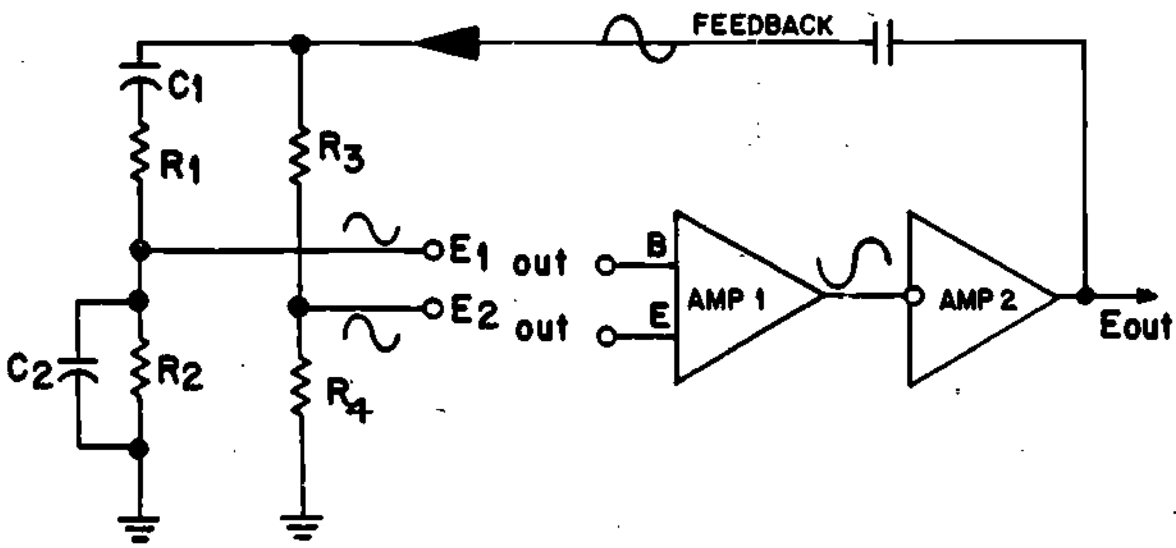


Figure 6

REDRAWN WIEN-BRIDGE OSCILLATOR

Two outputs from the bridge portion of the circuit are shown. They are identified as E1 and E2 out. The output from E1, the frequency determining portion of the bridge circuit is regenerative and is applied to the hase of the first amplifier. The degenerative feedback resulting from the action of the voltage divider is applied to the emitter of the first amplifier stage . Since this voltage is applied to the emitter of the first amplifier stage it opposes voltage applied to the base of the amplifier. Both regenerative and degenerative feedback are necessary in order to assure oscillation at the selected frequency.

Figure 5 shows frequency determining networks for frequencies below, above, and at Fo.

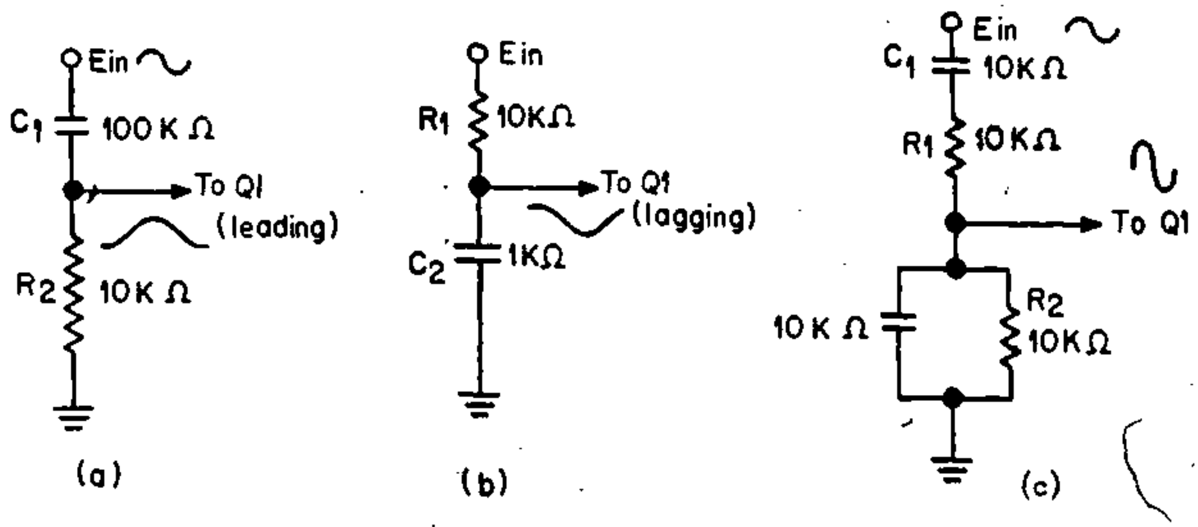


Figure 5

FREQUENCY DETERMINING NETWORK EQUIVALENTS

Look at the drawing shown in Figure 5a and notice that at frequencies below the oscillator frequency, the output of the frequency determining RC network is less than maximum with a leading phase angle. When C1 has a high reactance, the output of the RC circuit is low. As the frequency applied to the RC network increases, the output voltage also increases. The output voltage reaches maximum value at Fo, the correct oscillating frequency.

Figure 5b shows the effect of higher operating frequencies where the values of the reactance are less. In this case capacitor C2 becomes the controlling reactance. Recall, that in a parallel circuit the smallest resistance or reactance controls the circuit. Therefore, when the oscillator frequency is greater than Fo, the parallel combination of R2-C2 causes the output voltage to be less than at the operating frequency with a lagging phase angle.

In Figure 5c the equivalent circuit is shown for Fo. At the operating frequency the reactance of CI and C2 compensate for each other. As a result of this the equivalent circuit is purely resistive and no phase shift occurs. The output voltage then is maximum and greater than the degenerative voltage, provided by the other leg of the bridge. Because the circuit is operating at Fo and maximum regenerative feedback voltage is provided. Because this feedback voltage is greater than the degenerative feedback, oscillation occurs and is sustained. Make sure you understand how the frequency determining portion of the bridge circuit operates before proceeding further with this lesson.

Figure 8 shows the schematic for the complete Wien-bridge oscillator circuit. In addition to the bridge circuit the schematic for the two amplifier circuits which effect the 360° phase shift are shown.

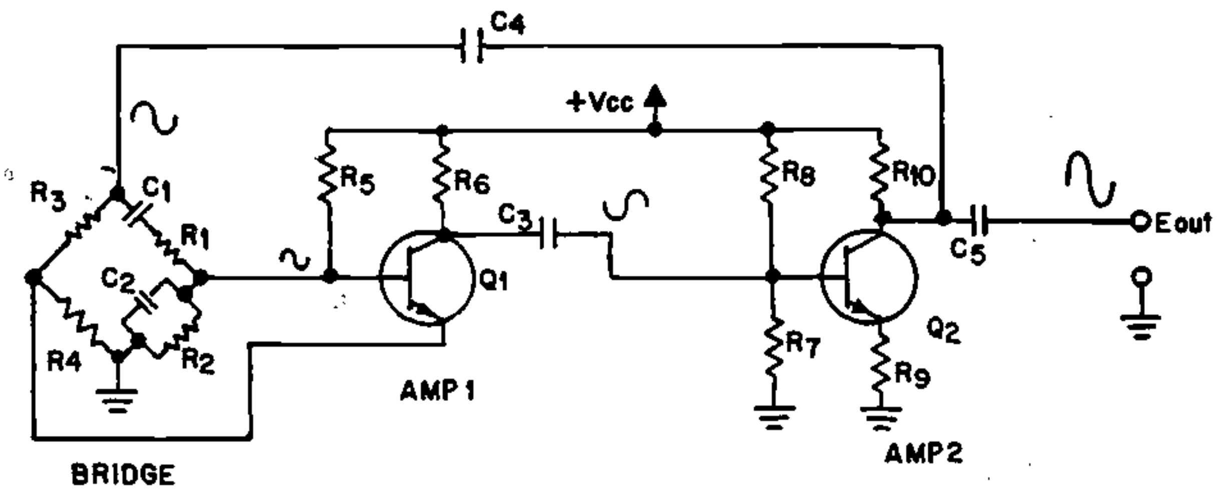


Figure 8

WIEN-BRIDGE OSCILLATOR CIRCUIT

The amplifiers in this circuit are biased to operate in Class A service. This class of operation causes the transistor to conduct during the entire input cycle and produces a distortion free output. Again notice that the regenerative feedback is connected to the base of QI and that the degenerative is connected to the transistor's emitter. Therefore, the feedback applied to the emitter opposes the feedback which is applied to the base of the transistor. Study the schematic again and notice that the phase shift provided by each of the amplifier stages is also shown.

The drawing shown in Figure 7 shows the relationship of the regenerative and degenerative feedbacks to the output frequency or frequency of operation (Fo).

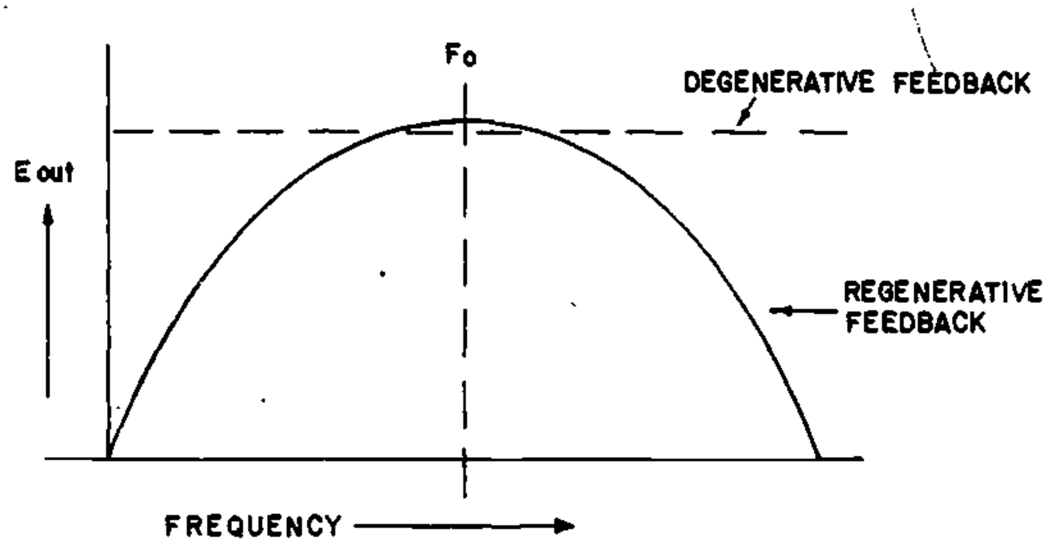


Figure 7

FREQUENCY RELATED TO Fo

The degenerative feedback is represented with a broken horizontal line. This voltage is constant and is not frequency sensitive like the regenerative feedback. The regenerative feedback is indicated with a solid line. Remember that the amount of degenerative feedback is determined by the action of the resistive voltage divider made up of R3 and R4. This voltage may be changed by changing the ratio between the resistors. The degenerative feedback voltage may be increased by increasing the resistance of R4 or decreasing the resistance of R3. Remember the ratio of two components determines the degenerative feedback voltage. Refer to the diagram and notice that the degenerative voltage exceeds the regenerative voltage at all frequencies except when the regenerative feedback is in phase with the oscillator output frequency. At this time oscillation occurs. Any time the degenerative feedback exceeds the regenerative feedback oscillations will cease.

The output amplitude stability of the Wien-bridge oscillator may be improved by adding an automatic gain control (AGC). The schematic shown in Figure 10 shows how this may be accomplished.

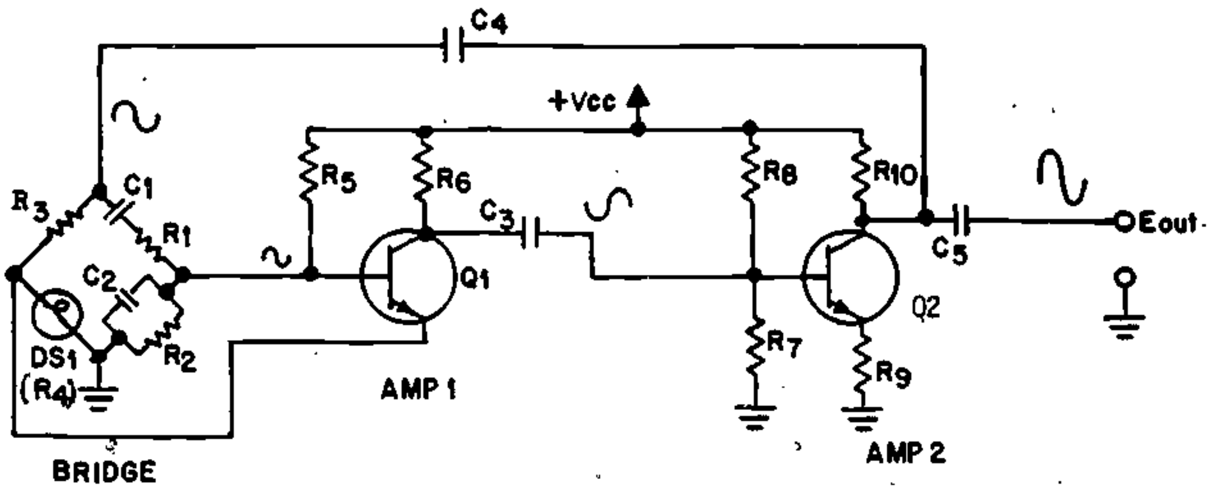


Figure 10

WIEN-BRIDGE OSCILLATOR WITH AGC

Notice that the schematic is identical to the schematic in the previous figure except a tungsten filament lamp has been substituted for resistor R4 in the voltage divider circuit. The resistance of the lamp varies as its temperature varies. When the temperature increases,the resistance of the lamp increases, and of course, when the temperature decreases the resistance will decrease. This type of lamp is said to have a positive temperature coefficient. Changes in resistance of R4 (DS1) results in changes in the degenerative feedback voltage. When the resistance of R4 increases there is an increase in the degenerative feedback voltage and more opposition to the regenerative feedback voltage applied to the base of the transistor. A decrease in the resistance of R4 results in a smaller degenerative feedhack voltage. To see how the lamp regulates, suppose the output voltage amplitude increases,this would cause more voltage across R4 with a resulting increase in the power consumed by it. When R4 gets hotter, its resistance increases. This causes more degenerative voltage to be fed to the emitter of the first amplifier, which decreases the gain of the stage, thus reducing the output to near normal.

Up to this point the explanation has focused on the bridge network which is the heart of the oscillator. You are already familiar with the other circuit components which make up a standard two-stage audio amplifier. You studied this in module 19 lesson 2. Now let's connect the bridge circuit to the two-stage amplifier and discuss the function of the remaining components. Look at Figure 9.

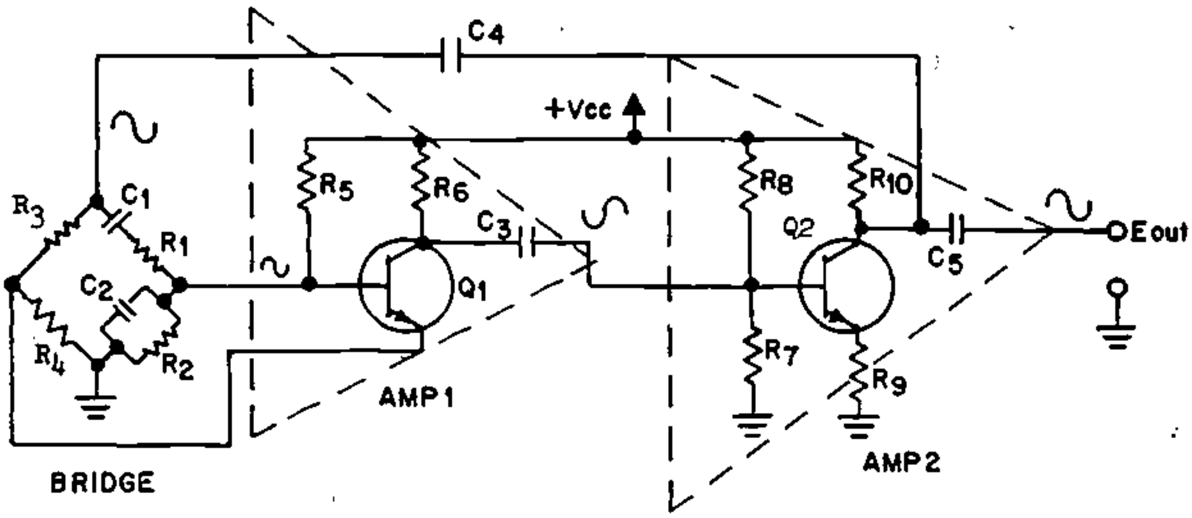


Figure 9

WIEN-BRIDGE OSCILLATOR CIRCUIT

Both amplifier stages are biased to operate in Class A service. You remember that this class of operation causes transistor conduction during the entire cycle of the input signal and produces a non-distorted output. R5 provides about 0.6 volt forward bias for Q1. R6 acts as the collector load for transistor Q1 to develop the output signal. R4, of course, is the emitter resistance for Q1 and the degenerative feedback component. C3 couples the signal, phase shifted by 180 degrees into the base circuit of Q2.

Biasing resistors R8 and R7 provide about 0.6 volt forward bias for Q2. R9 provides emitter stabilization while R10 acts as the collector load for Q2. C4 couples part of the output signal back to the bridge as feedback to sustain oscillations, while C5 couples the signal to the output terminals.

147

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, YOU MAY TAKE THE LESSON TEST. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH THE LEARNING CENTER INSTRUCTOR UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

For all intents and purposes the tungsten lamp functions like an AC voltage regulator and maintains a constant output amplitude. Another method for maintaining the constant output amplitude is to substitute a thermistor for the tungsten lamp. The thermistor is also heat sensitive and functions in the same manner as the lamp. These devices are available with either a positive or a negative temperature coefficient. The circuit application determines the type of temperature coefficient that is required. With the Wien-bridge oscillator circuit a thermistor with a positive temperature coefficient is used.

The schematic shown in Figure 11 is similar to the schematic shown in Figure 10 except capacitors C1 and C2 are variable. The frequency of the oscillator may be varied by changing, or varying, the capacitance of C1 and C2. Notice that the capacitors are ganged and because they are variable the circuit has a variable output frequency.

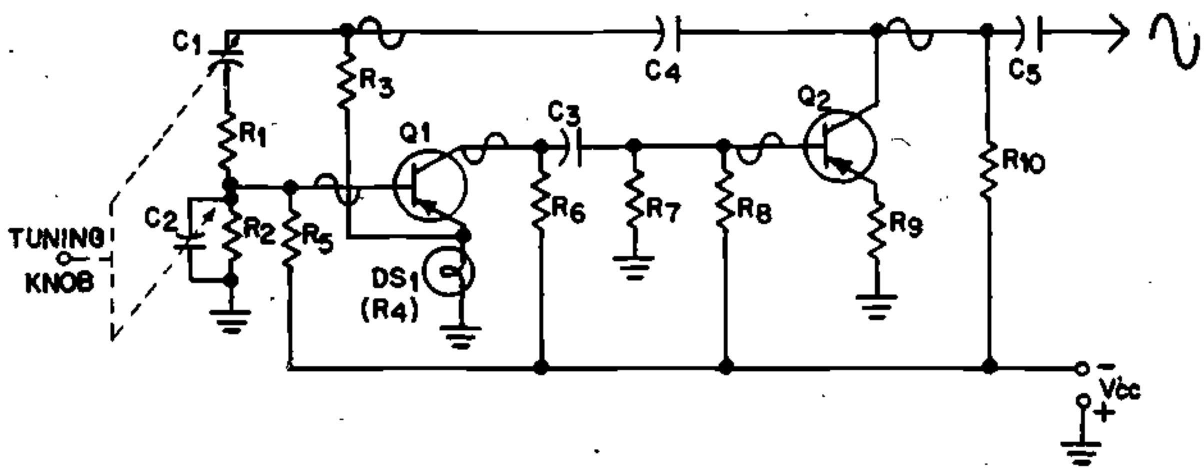


Figure 11

VARIABLE FREQUENCY WIEN-BRIDGE OSCILLATOR

Using variable capacitors in the bridge circuit allows the frequency to be varied from several Hz to over 200 kHz.

Again refer to the schematic and notice that PNP transistors may also be used in the Wien-bridge oscillator circuit. As is with other schematics waveforms have been superimposed to help you understand the operation of the total circuit.

OVERVIEW
LESSON 4

Blocking Oscillators

In this lesson you will learn about blocking oscillator circuits. You will learn how the blocking oscillator pulses, or triggers, radar equipment, computers, and other equipment where a timing pulse is required. You will learn how this type of oscillator produces output pulses at precise times. You will also learn how the inductive coupling within the oscillator provides the necessary regenerative feedback. Besides this, you will learn about the various components which make up the oscillator circuit and how these components function to provide accurate output pulses.

The learning objectives of this lesson are as follows:

TERMINAL OBJECTIVE(S):

32.4.59 When the student completes this lesson, (s)he will be able to TROUBLESHOOT and IDENTIFY faulty components and/or circuit malfunctions in blocking oscillator circuits when given a training device, pre-faulted circuit board, necessary test equipment, schematic diagram and instructions. 100% accuracy is required.

ENABLING OBJECTIVES:

When the student completes this lesson (s)he will be able to:

32.4.59.1 IDENTIFY the purpose of blocking oscillators by selecting the correct statement from a choice of four. 100% accuracy is required.

32.4.59.2 IDENTIFY the Pulse Width (PW), Pulse Repetition Time (PRT), Pulse Repetition Frequency (PRF), and Pulse Repetition Rate (PRR) of the output pulse of a blocking oscillator, given a waveform diagram, by selecting the correct value or statement from a choice of four. 100% accuracy is required.

32.4.59.3 IDENTIFY the functions of components and circuit operation of a free-running blocking oscillator circuit, given a schematic diagram, by selecting the correct statement from a choice of four. 100% accuracy is required.

32.4.59.4 IDENTIFY the circuit and output waveforms of a free-running blocking oscillator by selecting the correct waveform or statement from a choice of four. 100% accuracy is required.

MODULE THIRTY TWO

LESSON 4

BLOCKING OSCILLATORS

JULY 1980

LIST OF STUDY RESOURCES
LESSON 4

Blocking Oscillators

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following study resources:

Written Lesson presentation in:

Module Booklet:

Summary
Programmed Instruction
Narrative

Student's Guide:

Summary
Job Program Thirty Two-4 "Blocking Oscillators"
Progress Check

Additional Material(s):

Audio/Video Program Thirty Two-4 "Free Running Blocking Oscillators"

Enrichment Material(s):

Electronics Installation and Maintenance Book, EIMB, (Electronic Circui' ·) NAVSHIPS 0967-000-120
Basic ectronics Vol. 1, NAVPERS 10087-C

YOU MAY USE ANY, OR ALL, RESOURCES LISTED ABOVE, INCLUDING THE LEARNING CENTER INSTRUCTOR; HOWEVER, ALL MATERIALS LISTED ARE NOT NECESSARILY REQUIRED TO ACHIEVE LESSON OBJECTIVES. THE PROGRESS CHECK MAY BE TAKEN AT ANY TIME. BEFORE STARTING THE NEXT LESSON YOU WILL BE REQUIRED TO COMPLETE THE JOB PROGRAM, PASS THE LESSON TEST, COMPLETE THE FAULT ANALYSIS, PRACTICE TROUBLESHOOTING AND PASS THE PERFORMANCE TEST.

32.4.59.5 IDENTIFY the causes of and techniques used to eliminate overshoot or ringing in a blocking oscillator circuit by selecting the correct statement from a choice of four. 100% accuracy is required.

32.4.59.6 MEASURE and COMPARE waveforms and voltages in a blocking oscillator cirucit given a training device, circuit boards, test equipment and proper tools, schematic diagrams, and a job program containing reference data for comparison. Recorded data must be within limits stated in the job program.

32.4.59.7 IDENTIFY the faulty component or circuit malfunction in a given blocking oscillator circuit, given a schematic diagram and failure symptoms, by selecting the correct fault from a choice of four. 100% accuracy is required. *

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*This objective is considered met upon successful completion of the terminal objective.

BEFORE YOU START THIS LESSON, READ THE LESSON LEARNING OBJECTIVES AND PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

The pulse transformer differs from other transformers in that it has two secondary windings. The second secondary winding is called a tertiatry winding. Tertiary means third. The three windings of the pulse transformer are wound on the same iron core in such a way that voltages are induced into both the secondary and tertiary windings simultaneously. Refer to the figure and notice that phasing dots are shown. Therefore, the voltage polarity of pins 1, 4, and 6 is identical. The pulse transformer is designed and constructed in a special way so it saturates at a low current level. Once the transformer is saturated, any futher increase in current through the primary has no effect on the secondary output voltage. This is necessary if the blocking oscillator is to function properly.

The schematic diagram shown in Figure 2 is that of a blocking oscillator.

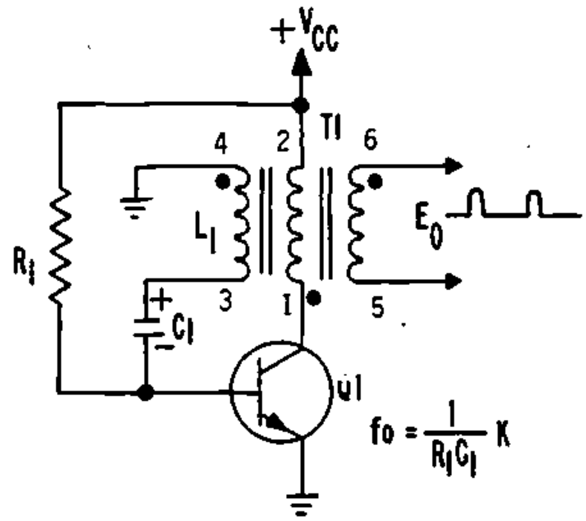


Figure 2

BASIC BLOCKING OSCILLATOR CIRCUIT

In may ways, this circuit is similar to the Armstrong oscillator circuit. The major difference between the two oscillator circuits is in the frequency determining circuitry. Whereas the frequency of the Armstrong oscillator is determined by a tank circuit, the blocking oscillator output frequency depends on the RC network made up of RI and CI. In both cases, regenerative feedback is necessary in order to intiate and sustain oscillation. With the blocking oscillator, regenerative feedback is provided by the inductive coupling of the transformer's primary and secondary. Forward bias is provided by RI, which is connected between Vcc and the base of transistor QI, to provide initial conduction of QI.

SUMMARY
LESSON 4

Blocking Oscillator

When you studied oscillators previously, you learned about oscillators that provide sine-wave outputs. The blocking oscillator is a special type of oscillator that produces a short duration, pulse output waveform. The pulse output waveform of the blocking oscillator is used in radar equipment, computers, and other equipment where trigger pulses are required. The blocking oscillator generates a very narrow output pulse.

There are a number of terms that you should become familiar with prior to proceeding with the lesson on blocking oscillators. These terms, listed below, are also used with radar equipment.

PULSE WIDTH (PW) Pulse width is the time from the start of the pulse to the end of the pulse.

PULSE REPETITION TIME (PRT) Pulse repetition time is the time from the start of one pulse to the start of the next pulse. It is measured from the leading edge of one pulse to the leading edge of the next pulse.

PULSE REPETITION FREQUENCY (PRF) Pulse repetition frequency refers to the frequency at which pulses occur. The frequency is usually stated in cycles per second.

PULSE REPETITION RATE (PRR) Pulse repetition rate is the number of pulses per second (PPS).

The blocking oscillator uses a special type of transformer. This transformer is constructed in such a way that it passes a square wave or pulse with a minimum amount of distortion. The transformer is called a pulse transformer. The schematic diagram for the pulse transformer is shown in Figure 1.

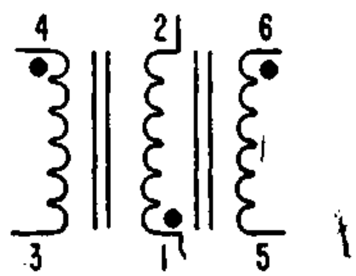


Figure 1

PULSE TRANSFORMER SCHEMATIC SYMBOL

The output waveform of the circuit across terminals 5 and 6 of the transformer is shown in Figure 3.

Figure 3

BLOCKING OSCILLATOR OUTPUT—TERTIARY WINDING

Examine the waveform and notice the inductive overshoot or ringing effect. This is an undesirable output resulting from the rapid current changes through the transformer windings. Because these damped oscillations may cause problems in other circuits associated with the blocking oscillator, it is necessary to eliminate this inductive overshoot or ringing.

One technique that is commonly used to eliminate the inductive overshoot or ringing, is to use clamping diodes as shown in Figure 4.

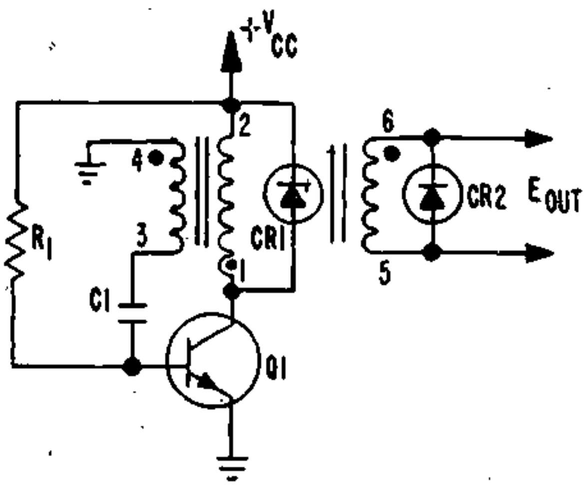


Figure 4

BLOCKING OSCILLATOR WITH CLAMPING DIODES

Refer again to the schematic shown in Figure 2. Because of the positive potential resulting from the action or R1, transistor Q1 is forward biased. As a result of this bias, when power is applied the transistor conducts. Since the resistance between the emitter and collector of Q1 is reduced, current now flows from ground through Q1, the primary of the transformer T1, and to Vcc. This results in a negative polarity at pin 1 and a positive polarity at pin 3 due to the transformer action. The positive signal from pin 3 is applied to the base of Q1 and increases the transistor's forward bias and the transistor conducts more. This action continues until the transistor or the pulse transformer reach the point of saturation. Since the pulse transformer is designed to saturate quite readily, the transformer reaches the point of saturation before the transistor.

At the same time current flows through Q1, capacitor C1 charges to a voltage equal to the secondary voltage of the pulse transformer. When the capacitor is fully charged, the current between the base and emitter of Q1 is reduced to a point where the transistor can no longer conduct. In effect, the transistor is cut off at this time. In other words, when the charge on capacitor C1 reaches maximum, the transistor cuts off.

The capacitor charge at this time is equal to the peak secondary voltage of the transformer's secondary (pin 3-4). At this time, since transistor conduction has stopped, the primary magnetic field of the transformer collapses. Remember from your study of inductors that an inductor opposes a change in current and therefore, in this case, the inductance will attempt to keep current flowing in the same direction. When the magnetic field of the transformer primary collapses, the voltage across capacitor C1 and transformer secondary (3 and 4) series aid each other and exceed the voltage at Vcc. Because the secondary voltage of the transformer is series aided by C1's voltage, the potential applied to the base of Q1 is now negative. At this time the transistor becomes reverse biased.

Q1 remains cut off, or blocked by this reverse bias until capacitor C1 discharges to a point where the voltage at Vcc exceeds C1's potential. Because a transistor is blocked for a significant amount of time during each cycle of operation, the circuit is called a blocking oscillator circuit. The time required for the capacitor to discharge is determined by the time constant resulting from the interaction of R1 and C1. If you have difficulty understanding how an RC network functions refer to Module 11. Eventually the capacitor discharges to a point where the positive Vcc voltage is again applied to the base of Q1. When this happens the transistor is again forward biased, it conducts and the transformer action produces regenerative feedback. The cycle repeats and once again the circuit oscillates.

The basic difference between this circuit and the blocking oscillator circuit which you previously studied is that terminal 4 of transformer T1 is returned to Vcc vice ground. An arrangement of this type removes the Vcc power source from the discharge path of the capacitor and improves the total stability of the circuit. Other than this difference, the operation of the NIDA blocking oscillator is essentially the same as a basic blocking oscillator circuit. In this case, notice that resistors R2, R3 and R4 function to dampen part of the undesirable oscillation of the transformer resulting from rapid current variation.

There are several variations of the basic circuit ; for example, triggered, synchronized, divided (count-down) versions of the oscillator circuit. The basic distinction between these circuits and the basic circuit is that the variations require input triggers.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, PROCEED TO THE JOB PROGRAM. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH THE LEARNING CENTER INSTRUCTOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

In this example, a clamping diode CR1 is placed directly across terminals 1 and 2 of the transformer's primary. When Q1 cuts off, this diode becomes forward biased and the voltage across terminals 1 and 2 of the transformer reverses polarity. Because diode CR1 has a low resistance when forward biased, the inductive overshoot voltage and the ringing is quickly damped out.

Another method often used for reducing the ringing is to connect a diode across the output winding of the pulse transformer. This is also shown in Figure 4. This diode, diode CR2, becomes forward biased whenever the output voltage at terminal 6 is negative in relation to terminal 5. Because of the diode action, the output is limited, or clammped, to within a few tenths of a volt. This results in an output waveform that is relatively free of inductive overshoot or ringing.

Another means of reducing the ringing action of the transformer is to use resistive loads commonly called dampers. In this case, small value resistors are placed in series or shunt with the transformer secondary or tertiary windings. Resistors used in this way absorb some of the oscillations caused by the rapid collapse of the transformer's magnetic field. It is also possible to use both resistors and clamping diodes. Circuit design characteristics determine whether clamping diodes and resistive loads are used together or independently.

The schematic diagram shown in Figure 5 is a slight variation of the basic blocking oscillator circuit. This is the schematic for the NIDA blocking oscillator which you will use and become familiar with when you complete the job program associated with this lesson.

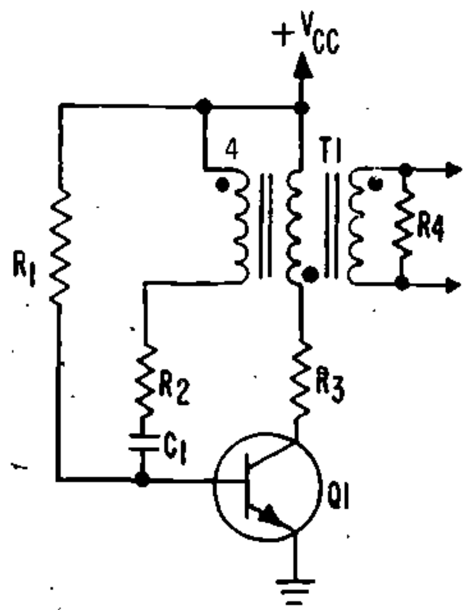


Figure 5

NIDA BLOCKING OSCILLATOR SCHEMATIC

(2.) The blocking oscillator, which is sometimes called a pulse repetition frequency (PRF) generator, has a nonsinusoidal output waveform. This oscillator is used to trigger circuits in electronic equipments such as radar, computers, and television. It is used where pulses are needed to trigger or control other circuits.

One type of oscillator that provides pulses or triggers to control other types of electronic circuitry is a(n) __________ oscillator.

a. Colpitts

b. Armstrong

c. Blocking

d. RC network

---

c. Blocking

(3.) The drawing shown in Figure 2 is a block diagram for a blocking oscillator together with possible output waveforms.

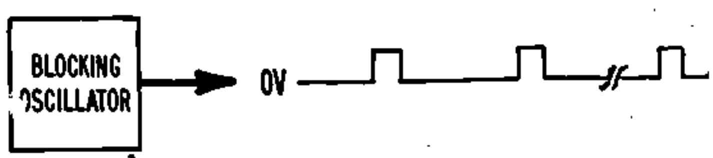


Figure 2

FREE RUNNING BLOCKING OSCILLATOR OUTPUT

PROGRAMMED INSTRUCTION
LESSON 4

BLOCKING OSCILLATOR

TEST FRAMES ARE 6, 15, AND 21. PROCEED TO TEST FRAME 6 AND SEE IF YOU CAN ANSWER THE QUESTIONS. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

1. In your previous study of oscillators you learned about oscillators that provide sine-wave outputs. Mention was also made of oscillators which provide outputs which are not sinusoidal. You studied one such oscillator called a multivibrator in Module 23. Recall that the output from a multivibrator circuit is a square or rectangular wave form. Figure 1 shows the block diagram for the multivibrator and its output waveform.

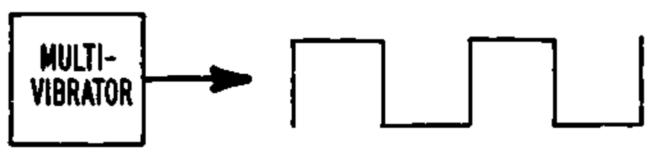


Figure 1

FREE RUNNING MULTIVIBRATOR OUTPUT

No response required.

PULSE WIDTH (PW) - Pulse width is the time from the start of the pulse to the end of the pulse. This is shown in Figure 3 with times T1 to T2 and times T3 to T4. This term is sometimes referred to as pulse duration.

PULSE REPETITION TIME (PRT) - PRT is the time from the start of one pulse to the start of the next pulse. It is measured from the leading edge of one pulse to the leading edge of the next pulse. It is sometimes referred to as pulse rest time.

Refer to the drawing shown in Figure 4 and label the Pulse Width and the Pulse Repetition Time.

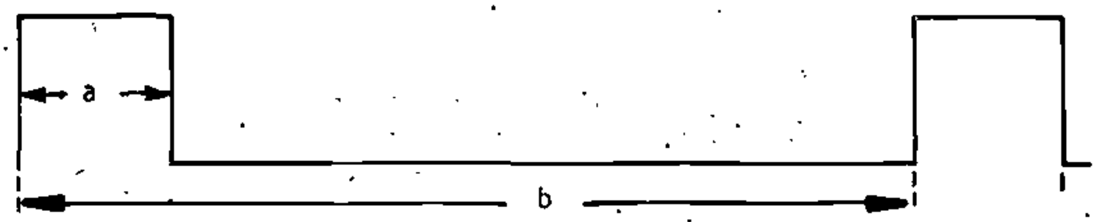


Figure 4

a. ____________________

b. ____________________

---

a. Pulse Width

b. Pulse Repetition Time

5. PULSE REPETITION FREQUENCY (PRF) - refers to the frequency at which pulses occur. Frequencies are stated in cycles, kilocycles, or megacycles. For example: 15 kHz, 2.5 kHz.

The output pulse rate of the blocking oscillator circuit varies depending on the particular application. With this type of circuitry, pulse rates generally range from 20 to 2000 pulses per second.

The blocking oscillator generates a narrow output pulse. The "on time" is relatively short whereas the "off time" or rest time is quite long. This will be discussed in greater detail in subsequent frames.

The output pulse rate of a blocking oscillator ranges from:

a. 1 to 10,000 pulses per second.

b. 20 to 2,000 pulses per second.

c. 1,000 to 50,000 pulses per second.

d. 1 to 10 pulses per second.

---

b. 20 to 2,000 pulses per second

4. Several terms are used in relation to blocking oscillators which you should become familiar with. This terminology is also used with radar equipment. These concepts or terms are reflected in Figure 3.

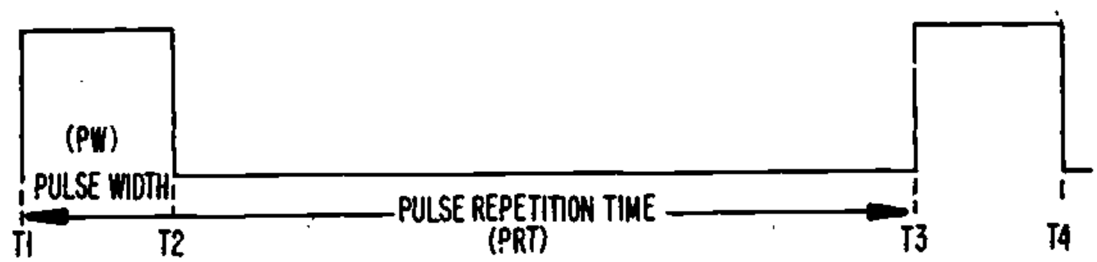
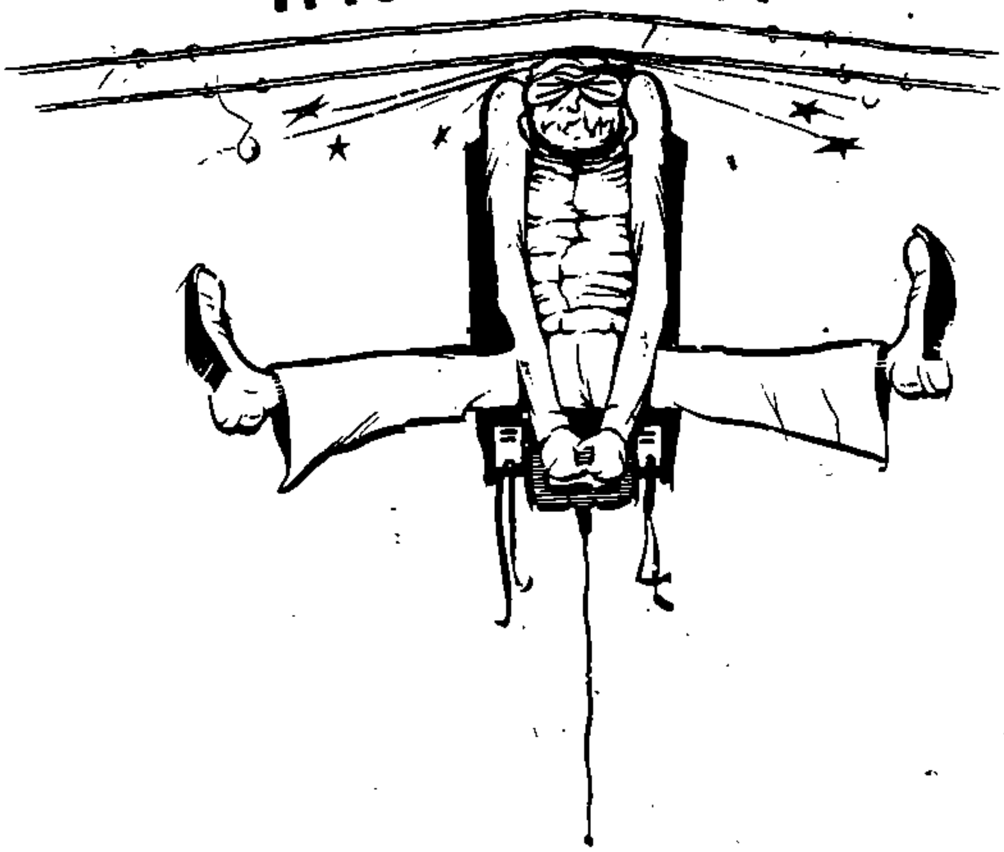


Figure 3

PULSE TERMINOLOGY

Trial and Error



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<u>PULSE REPETITION RATE</u> (PRR) - The pulse repetition rate is the number of pulses per second.(pps). For example: If the PRF is 10 kHz then the PRR would be 10,000 pps.

To find PRF or PRR use the formula: PRF(PRR) equals 1÷PRT.

For example, if the Pulse Repetition Time is 2,000 microseconds then the frequency or PRF would be found as follows:

$$PRF = \frac{1}{PRT} = \frac{1}{2000\ \mu s} = \frac{1}{2000 \times 10^{-6}} = \frac{1}{2 \times 10^{-3}} = .5 \times 10^{3} \text{ or } 500 \text{ Hz or } 500 \text{ pps.}$$

If the Pulse Repetition Time is 1600 microseconds then the frequency or PRF is:

a. 500

b. 625

c. 1250

d. 2500

---

b. 625

a. PW equals 10 μsec.

b. PRT equals 100 μsec.

c. PRF equals 10 kHz

d. PRR equals 10,000 pps

IF YOUR ANSWERS MATCH THE CORRECT ANSWERS YOU MAY GO TO TEST FRAME 15, OTHERWISE GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE AGAIN BEFORE TAKING TEST FRAME 6 AGAIN.

7. A blocking oscillator uses a special type of transformer. This transformer is constructed in such a way that it passes a square wave or pulse with a minimum amount of distortion. This transformer is called a pulse transformer. The schematic diagram shown in Figure 5 is that of a common type pulse transformer used in blocking oscillators.

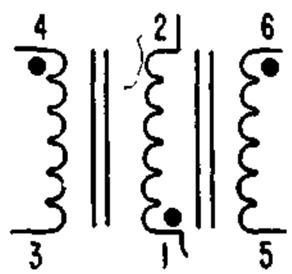


Figure 5

PULSE TRANSFORMER SCHEMATIC SYMBOL

Notice that this transformer has three windings. The 1-2 winding is the primary winding and the 3-4 winding is the transformer secondary winding. The other winding, 5-6, is called a tertiary winding. A tertiary winding is a

6. THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE PAGE FOLLOWING THE TEST QUESTIONS. REFER TO THE DRAWING BELOW IN ORDER TO ANSWER THE TEST QUESTIONS.

1. With a time base of 10 μsec/division, determine the following quantities:
   a. Pulse Width (PW)
   b. Pulse Repetition Time (PRT)
   c. Pulse Repetition Frequency (PRF)
   d. Pulse Repetition Rate (PRR)

(9.) The schematics shown in Figure 6 are for a free running blocking oscillator and a basic Armstrong oscillator.

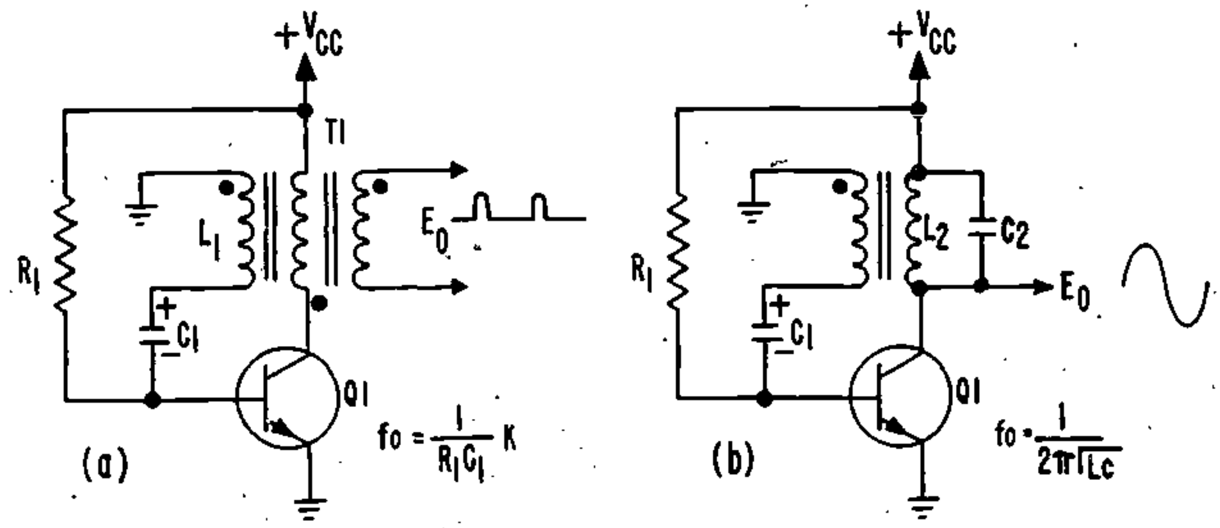


Figure 6

BLOCKING AND ARMSTRONG OSCILLATOR CIRCUITS

As you study the schematics notice the many similarities. The major difference is in the frequency determining circuitry. The frequency of the Armstrong oscillator is determined by the tank circuit whereas the blocking oscillator output pulse frequency depends on the values of R1 and C1. In both cases regenerative feedback is necessary to initiate and sustain oscillation. The blocking oscillator provides the regenerative feedback by the inductive coupling of the transformers primary and secondary, and forward bias provided by RI connected between VCC and the base of Q1.

third winding. The three windings are wound on the same iron core in such a way that voltages are induced into both the secondary and tertiary winding at the same time.

A Pulse Transformer is made up of ____________ windings and the extra winding is called a ____________ winding.

a. 2, binary

b. 2, tertiary

c. 3, binary

d. 3, tertiary

---

d. 3, tertiary

(8.) Refer again to the schematic shown in Figure 5. Notice that phasing dots are shown. Therefore, the voltage polarity at pins 1, 4, and 6 are identical. The pulse transformer is constructed in a special way. It is designed to saturate at low current levels. When the transformer is saturated, further increases in current throught the primary winding do <u>not</u> result in an increase in the secondary output voltage. This is a desirable condition necessary for the operation of blocking oscillators which will be discussed in subsequent frames.

No response required

In addition to the schematic a waveform plotted against time is also shown. This technique will be used in this frame and subsequent frames to explain the total operation of the Blocking oscillator circuit. Since transistor Q1 is forward biased, as a result of the positive potential on its base resulting from the action of R1, when power is applied the transistor conducts. At this time the resistance between the emitter and collector of Q1 is reduced. Current now flows from ground through Q1, the primary of transformer T1, to VCC. At this time there is a negative polarity at pin 1 and a positive polarity at pin 3 due to transformer action. This positive signal on the base of Q1 increases the transistor's forward bias and the transistor conducts more.

The increased transistor conduction results in a further increase in the forward bias of the transistor and this action continues until the transistor or the pulse transformer reaches the point of saturation. Because ulse transformer is designed to saturate quite readily, the transformer reaches the saturation point before the transistor.

The component which achieves saturation first in a blocking oscillator circuit is the:

a. transistor

b. resistor

c. capacitor

d. pulse transformer

---

d. Pulse Transformer

The output waveform of an Armstrong oscillator is a ___________ wave, and the output of a blocking oscillator is a _____________.

a. sine, pulse

b. pulse, sine

c. sine, sine

d. pulse, pulse

---

a. Sine, Pulse

---

10. The schematic diagram shown in Figure 7 is that of a basic blocking oscillator circuit.

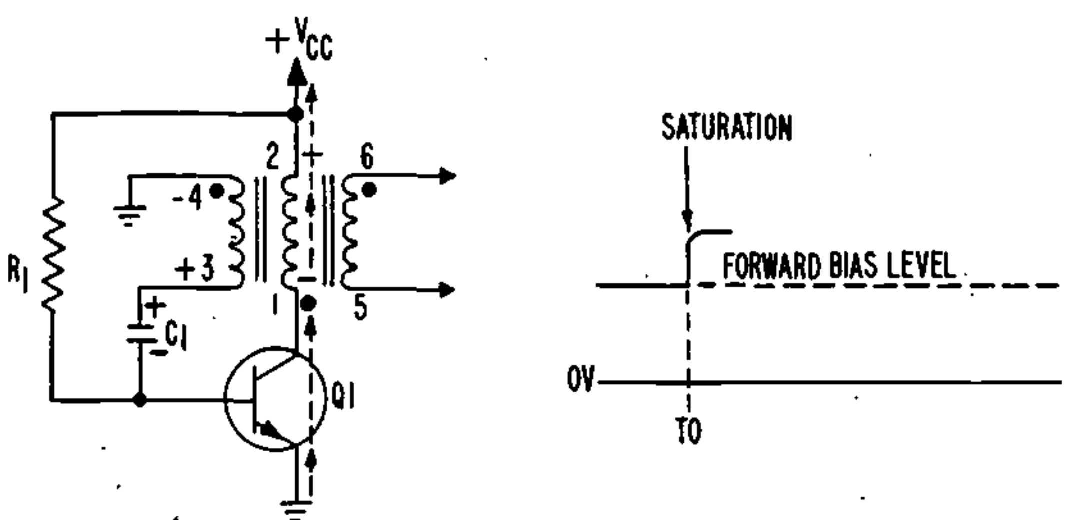


Figure 7

BLOCKING OSCILLATOR ACTION

When capacitor C1 is fully charged

a. the conduction of Q1 increases.

b. Q1 is forward biased and conducts more.

c. transistor Q1 continues to conduct until the capacitor C1 discharges.

d. the current between the base and emitter of Q1 is so small that the transistor stops conducting.

---

d. the current between the base and emitter of Q1 is so small that the transistor stops conducting

---

12. The schematic shown in Figure 9 is also for a blocking oscillator. In addition to the schematic, a waveform is also shown. This waveform indicates the effect a complete charge on C1 has on the transistor.

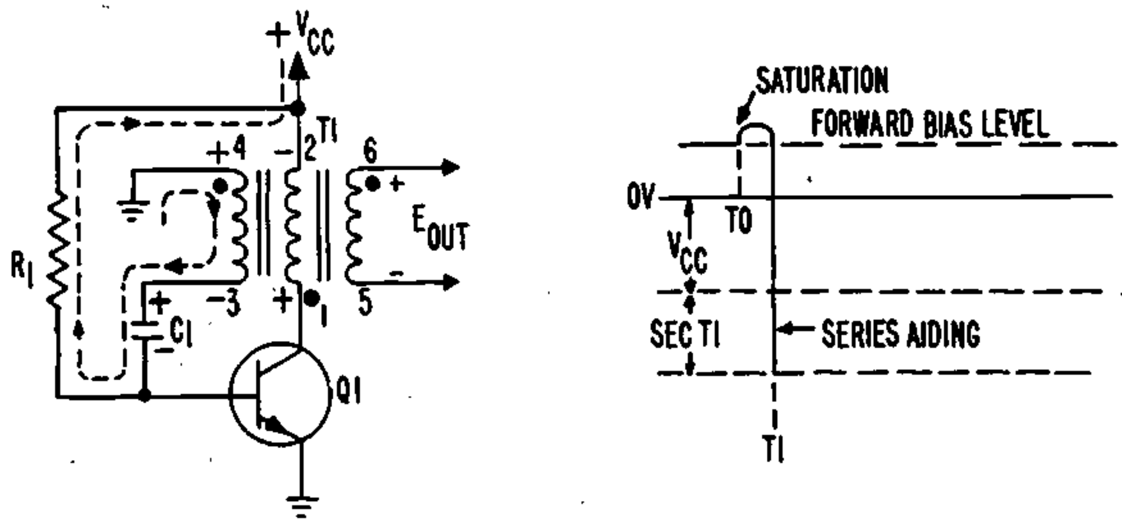


Figure 9

BLOCKING OSCILLATOR ACTION

(11) At the same time that current flows through Q1, C1 charges to a voltage equal to the secondary voltage of the pulse transformer T1. The waveform shown to the right of the schematic in Figure 8 illustrates this.

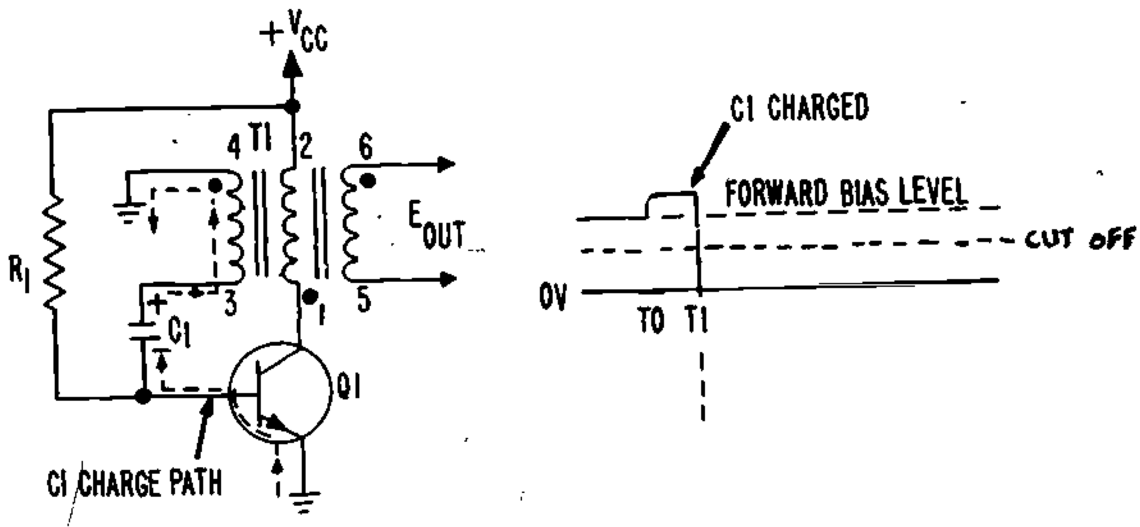


Figure 8

BLOCKING OSCILLATOR ACTION

Because the base-emitter junction of Q1 is heavily forward biased, the junction resistance is very small. Therefore, the RC charge time of C1 is short as indicated by the waveform at the right of Figure 8. As the current through Q1 becomes smaller, the charge on C1 approaches the secondary voltage of the transformer. When the capacitor achieves a full charge, the current between the base and emitter of Q1 is reduced to a point where the transistor no longer conducts. In effect the transistor is cut off at this point.

(13.) Figure 10 shows the components which determine the length of time that the transistor will be blocked. Besides this, a waveform showing the discharge of capacitor C1 is reflected in the figure.

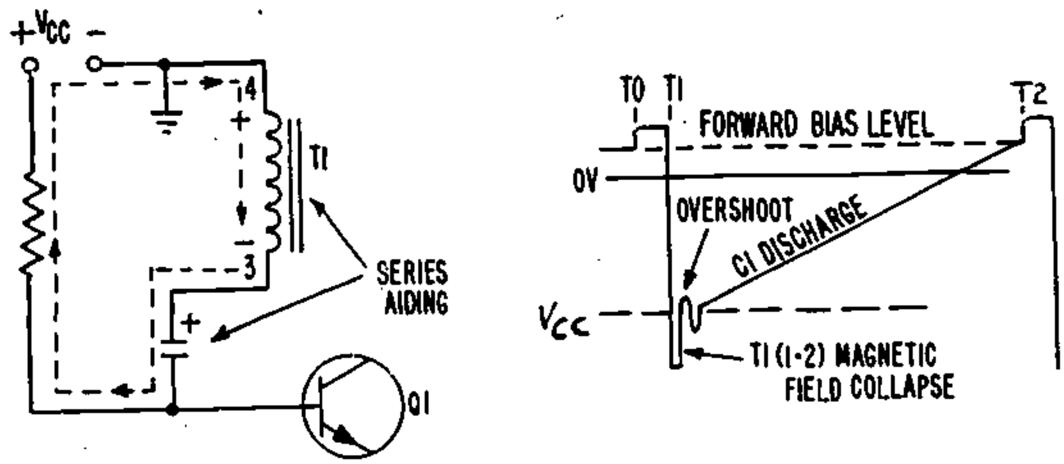


Figure 10

Q1 BLOCKING ACTION

Because Q1 is cut off, or blocked, for a significant amount of time during each cycle of operation, the circuit is called a blocking oscillator. Notice that at time T1 the magnetic field surrounding the transformer primary, windings 1-2, collapses and the voltage across terminals 3 and 4 falls to zero. The charge on capacitor C1 still holds the transistor in cut off. At this time, the capacitor discharges through R1 to Vcc, then from ground, through the transformer winding 3-4, into the positive side of the capacitor as indicated by the arrows. The time required for the capacitor to discharge is determined by the time constant of R1-C1. This was explained in Module 11.

When the charge on capacitor C1 reaches maximum, the transistor is cut off. At this time the primary of the transformer has a large stationary magnetic field of flux built up around it. Capacitor C1 has charged to the peak secondary voltage of the transformer across pins three and four. At this time the magnetic field across the primary (pins 1-2) of the transformer collapses. Recall from your study of inductors that an inductor opposes a change in current and therefore, in this case, the inductance will attempt to keep current flowing in the same direction. This action induces a voltage across terminals 1 and 2 of the transformer with polarities as indicated in the figure. At this time the induced voltage across terminals 1 and 2 of the transformer is transformer coupled to pins 3 and 4 as indicated in the drawing. Examination of the drawing will reveal that at this time the voltage across capacitor C1 and transformer pins 3 and 4 are series aiding and greater than the voltage at Vcc. At this point, the base of transistor Q1 is highly reverse biased by these two voltages and remains so until forward bias is again applied to the base of the transistor. This occurs when the magnetic field of the primary transformer winding, pins 1 and 2, collapse and C1 discharges.

Transistor Q1 is blocked by the

a. charge on capacitor C1 and the potential of the transformer secondary (pins 3-4).

b. voltage across C1 only.

c. Primary (pins 1-2) voltage of the pulse transformer.

d. tertiary voltage of the pulse transformer.

---

a. charge on capacitor C1 and the potential of the transformer secondary (pins 3-4)

15. THIS IS A TEST FRAME. COMPLETE THE QUESTIONS AND COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE PAGE FOLLOWING THE TEST QUESTIONS.

1. A blocking oscillator uses a ____________ transformer .

   a. filament

   b. power

   c. flyback

   d. pulse

2. The third winding of the transformer used in a blocking oscillator is called a _____________ winding.

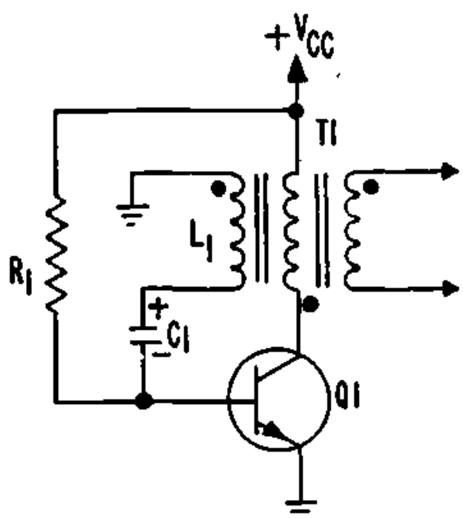
   a. secondary

   b. tertiary

   c. binary

   d. hexadecimal

REFER TO THE SCHEMATIC SHOWN BELOW WHEN ANSWERING QUESTION 3 AND 4.



The discharge time of C1 is primarily determined by the

a. inductance of the transformer primary (pins 1-2).

b. forward bias of Q1.

c. time constant of R1-C1.

d. capacitor voltage rating.

---

c. time constant of R1-C1

(14.) Refer to the waveform shown on the right side of Figure 10. Notice the discharge curve associated with C1. During the time the capacitor is discharging, a negative potential is applied to the base of the transistor. Because of this, the transistor cannot conduct. Eventually capacitor C1 discharges to a point where the positive Vcc voltage is felt on the base of Q1. At this time the transistor again becomes forward biased, conducts, and the transformer action produces regenerative feedback. This occurs at time point T2 as indicated in the drawing. At this time the cycle repeats and the circuit will repeat the process. The entire cycle completes one oscillation.

During the time the capacitor C1 is discharging, the transistor Q1 is

a. forward biased.

b. conducting.

c. cut-off.

d. oscillating.

---

c. cut off

---

1. d. pulse
2. b. tertiary
3. c. T.
4. d. value of R1 and C1

IF YOUR ANSWERS MATCH THE CORRECT ANSWERS YOU MAY GO TO TEST FRAME 21. OTHERWISE GO BACK TO TEST FRAME 7 AND TAKE THE PROGRAMMED SEQUENCE AGAIN BEFORE TAKING TEST FRAME 15 AGAIN.

16. The waveforms shown in Figure 11 are included to help you understand the operation of the blocking oscillator circuit.

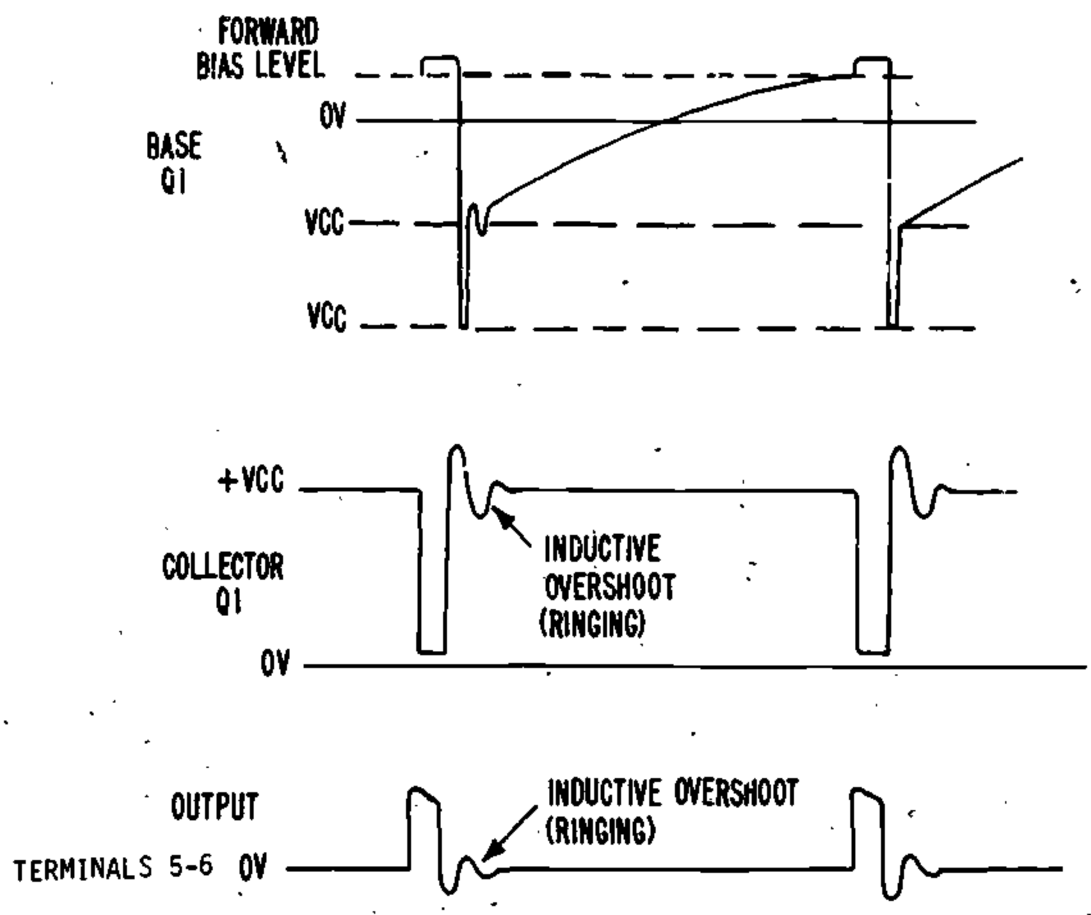


Figure 11
BLOCKING OSCILLATOR WAVEFORMS

3. The component which is designed to saturate in the schematic shown is

   a. R1

   b. C1

   c. T1

   d. Q1

4. The discharge time of C1 is determined primarily by the

   a. transformer primary

   b. transistor's forward bias

   c. wattage rating of R1.

   d. value of R1 and C1.

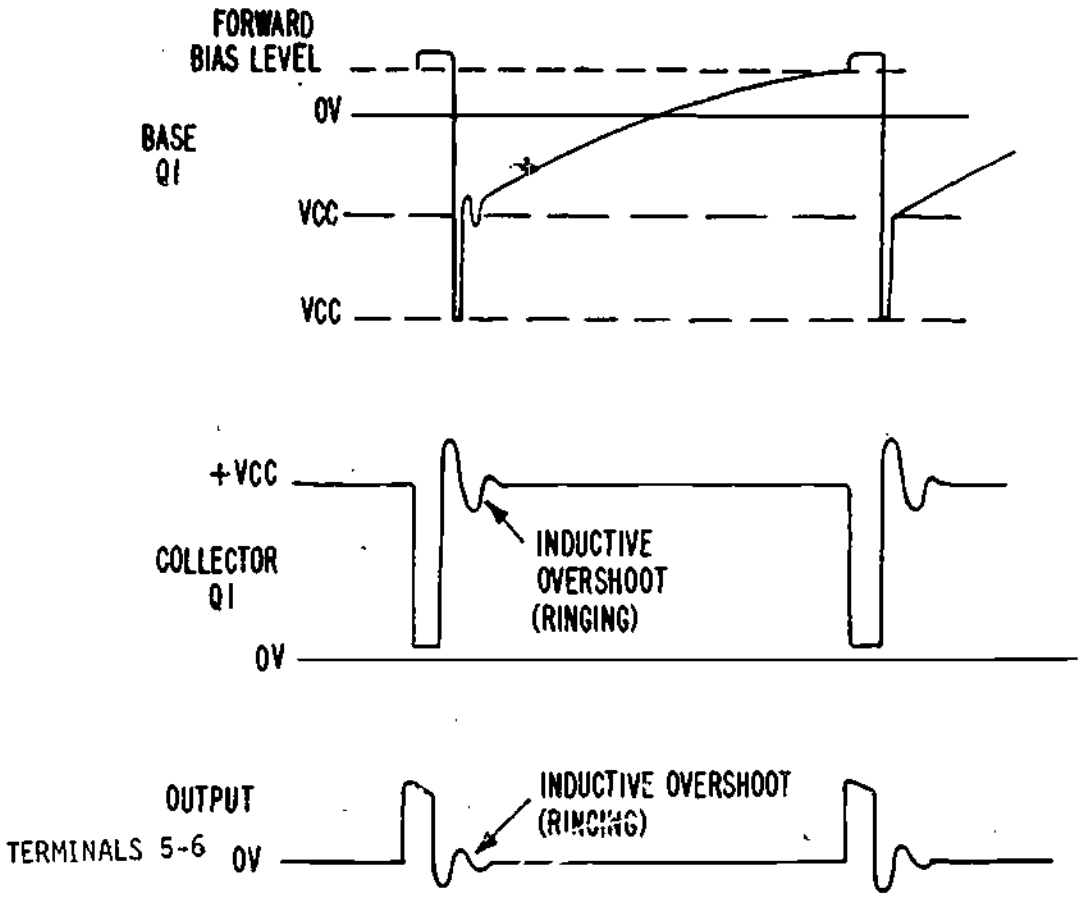


Figure 11

BLOCKING OSCILLATOR WAVEFORMS

Notice by referring to the bottom waveform that while the capacitor discharges the output ceases between terminals 5 and 6 or the tertiary terminals of the transformer. Examine the waveforms and notice the inductive overshoot or ringing effect. This undesirable output is the result of the rapid current changes through the transformer windings which are basically inductances. As you can see, the energy stored in the magnetic field is not completely absorbed as the field rapidly collapses, rather it functions to cause an induced voltage of opposite polarity across the transformer windings. Since these damped oscillations may cause problems with the other circuits associated with the blocking oscillator, the inductive overshoot or ringing must be eliminated. Methods for eliminating this are discussed in subsequent frames.

Each of the waveforms shows the potential in relation to a reference voltage. Notice that the top waveform indicates the potential at the base of transistor Q1, while the middle waveform shows the collector potential. The bottom waveform indicates the waveform at the output, or terminals 5 and 6, which form the tertiary winding of the pulse transformer. An understanding of how the various components function in relation to the waveforms will provide you with a better understanding of blocking oscillators. Look at the waveform associated with the base of transistor Q1. Recall that when the transistor is forward biased, capacitor C1 is charging. This is indicated by the waveform above the broken line designated as forward bias level. During this time the potential at Q1's collector is driven toward zero volts. This is shown by the collector waveform. Once the capacitor is fully charged, the capacitor is series aided by the secondary of the transformer Pins 3 and 4. At this time the negative voltage exceeds the positive voltage of Vcc, and therefore the transistor is no longer forward biased and does not conduct.

(18.) Another method of reducing the ringing is to connect a diode across the output winding of the pulse transformer. This is also shown in Figure 12. The diode becomes forward biased whenever the output voltage at terminal 6 swings negative in relation to terminal 5. Because of this diode action, the output is limited or clamped to within a few tenths of a volt. The waveforms shown in Figure 13 illustrate the output resulting from the uses of the clamping diodes.

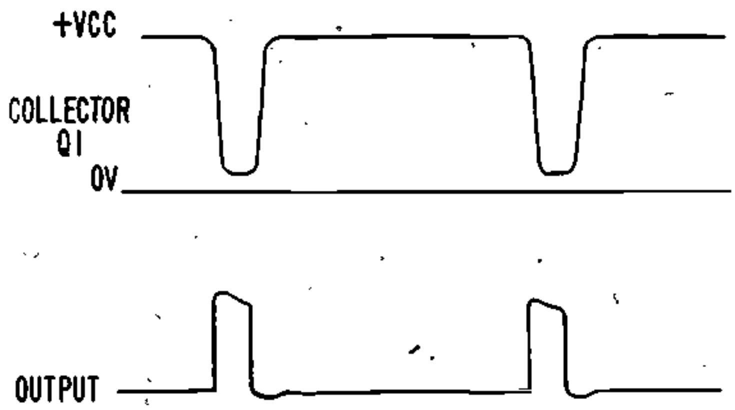


Figure 13

WAVEFORMS WITH CLAMPING DIODES

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no response required

no response required

(17.) There are two methods which are commonly used to eliminate the inductive overshoot or ringing. A common technique is to use a clamping diode as shown in Figure 12.

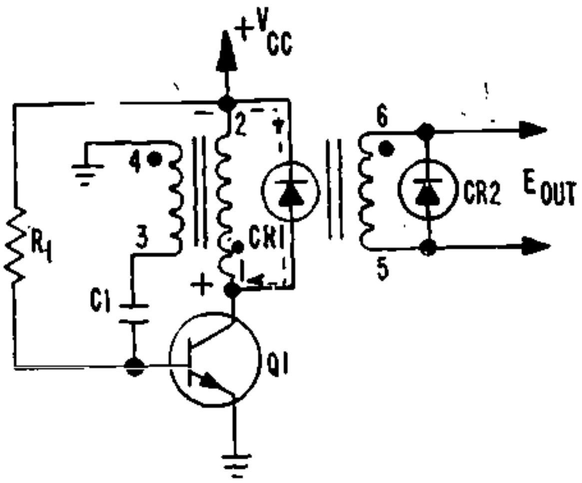


Figure 12

CLAMPING DIODES

In this example, a clamping diode, CR1, is placed directly across terminals 1 and 2 of the transformer's primary. This diode becomes forward biased when Q1 cuts off, and the voltage across terminals 1 and 2 of the transformer takes on polarity shown. Because CR1 has a low resistance when forward biased, this reduces the inductive overshoot voltage, and the coil energy is quickly damped.

A common method used for damping oscillations is to use

a. a larger capacitor.

b. a larger value resistor in the RC network.

c. clamping diodes.

d. an RC filter.

---

c. clamping diodes 153

(19.) Another technique for reducing the ringing action of the transformer is to use resistive loads commonly called "dampers". To accomplish this damping, small value resistors may be placed in series or in shunt with the transformer windings as shown in Figure 14.

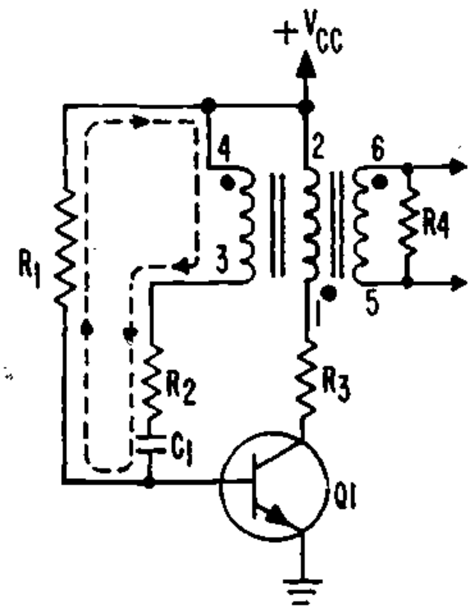
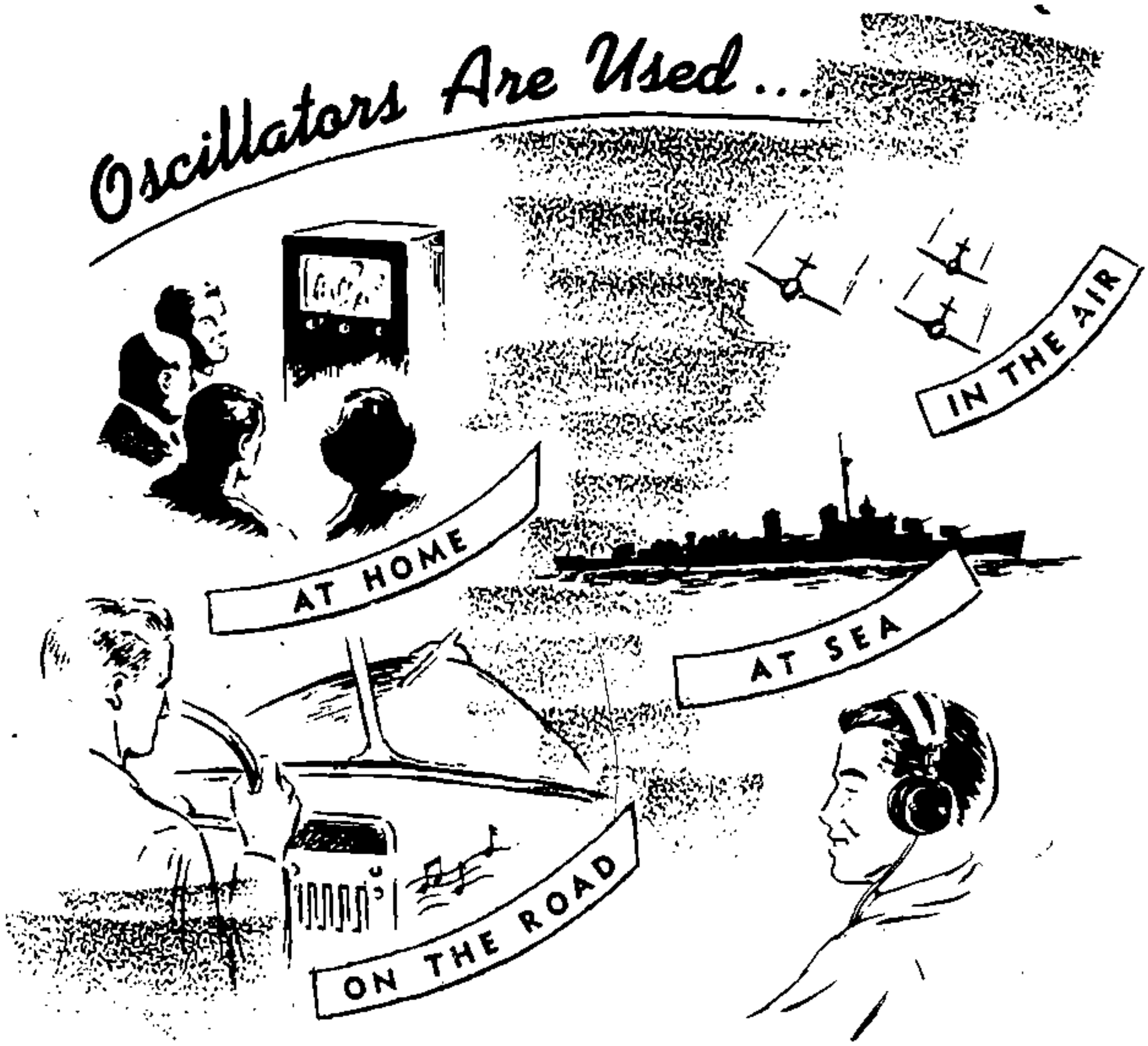


Figure 14

BLOCKING OSCILLATOR WITH DAMPING RESISTORS

In the schematic shown, resistors R2, R3, and R4 are used as damping resistors. These resistors absorb some of the oscillations caused by the rapid collapse of the transformer's magnetic fields. It is also possible to use resistors in conjunction with clamping diodes as shown in previous frames. Circuit design characteristics determine whether clamping diodes and resistive loads are used together or independently.


Oscillators Are Used ...
AT HOME
IN THE AIR
AT SEA
ON THE ROAD

(20.) The schematic diagram shown in Figure 15 shows a slight variation of the basic blocking oscillating circuit. This is schematic for the NIDA blocking oscillator which you will become familiar with when you complete the job performance associated with this lesson.

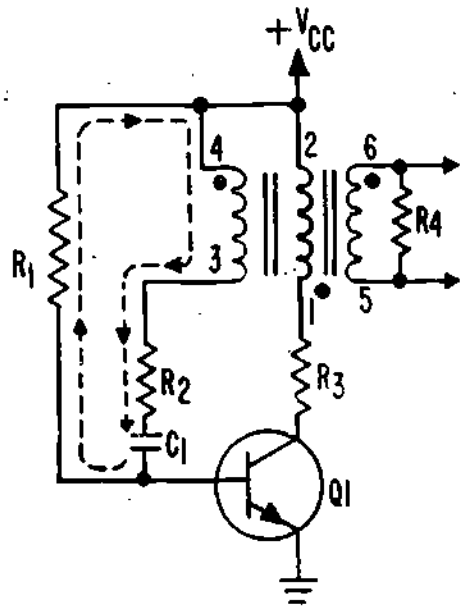


Figure 15

NIDA BLOCKING OSCILLATOR

One method that is used to reduce the ringing action of transformers in blocking oscillators is to

a. increase the forward bias of the transistor.

b. change the value of the capacitor in the RC network.

c. use resistors in series or in shunt with the transformer windings.

d use a filtering circuit.

---

c. use resistors in series or in shunt with the transformer windings.

187

(21.) THIS IS A TEST FRAME. COMPLETE THE TEST QUESTIONS AND THEN COMPARE YOUR ANSWERS WITH THE ANSWERS GIVEN AT THE TOP OF THE PAGE FOLLOWING THE QUESTIONS.

1. Ringing in pulse transformer is associated with the

   a. discharge of capacitors.

   b. rapid collapse of magnetic fields.

   c. transistor conduction time.

   d. transistor cut-off time

2. One method often used for reducing the ringing action of pulse transformers is to

   a. use larger capacitor in the RC network.

   b. increase the size of the resistor in the RC network.

   c. use an RC filter.

   d. use clamping diodes.

3. The output of a blocking oscillator is a ________________ waveform.

   a. sawtooth

   b. sine

   c. pulse

   d. trapezoidal

The difference between this circuit and the blocking oscillator circuits which you previously studied is that terminal 4 of the transformer TI is returned to Vcc vice ground. This arrangement removes the Vcc power source from the discharge path of the capacitor and improves the stability of the circuit. Besides this difference, the operation of the NIOA Blocking oscillator is the same as the basic circuit. Notice particularly the addition of damping resistors R2, R3, and R4, which function to dampen part of the undesirable oscillation of the transformer due to the rapid current variations. One additional point should be made about the free running blocking oscillator. There are several variations of the basic circuit, for example, triggered, synchronized, divider (countdown) versions of the free-running circuit. One basic distinction between these circuits and the basic free-running circuit is that all these variations require input triggers to operate properly.

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no response required

189

1. b. rapid collapse of magnetic fields

2. d. use clamping diodes

3. c. pulse

IF YOUR ANSWERS MATCH THE CORRECT ANSWERS YOU HAVE COMPLETED THE PROGRAMMED INSTRUCTION FOR LESSON 4, MODULE THIRTY TWO. OTHERWISE GO BACK TO FRAME 16 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 21 AGAIN.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, YOU MAY TAKE THE JOB PROGRAM. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH LEARNING CENTER INSTRUCTOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

191

PULSE WIDTH (PW) Pulse width is the time from the start of the pulse to the end of the pulse. This is shown in the diagram with times T1 to times T2 and time T3 to times T4. Sometimes this term is referred to as pulse duration.

PULSE REPETITION TIME (PRT) PRT is the time from the start of one pulse to the start of the next pulse. It is measured from the leading edge of the first pulse to the leading edge of the next pulse.

PULSE REPETITION FREQUENCY (PRF) PRF refers to the frequency at which pulse occur. These frequencies are usually stated in Hertz (cycles) or Kilo Hertz (kilocycles). For example: 100 Hz, 2.5 kHz.

PULSE REPETITION RATE (PRR) Pulse repetition rate is the number of pulses per second. (PPS) for example, when the PRF is 10 kHz, the PRR would be 10,000 PPS.

You should become familiar with the formula for determining pulse repetition frequency or pulse repetition rate. The formula is F equals $1 \div T$
For example, if the pulse repetition time is 1600 microseconds, then the pulse repetition rate or frequency would be equal to:

$$\frac{1}{PRT} = \frac{1}{1600\mu s} = \frac{1}{1600 \times 10^{-6}} = \frac{1}{1600} \times 10^{6} = \frac{1000}{1600} \times 10^{3} = .625 \times 10^{3}$$

$$= 625 \text{ pps} \quad = 625 \text{ Hz.}$$

The key component of the blocking oscillator circuit is a special transformer that passes a pulse with a minimum amount of distortion. This special transformer is called a pulse transformer. The schematic shown in Figure 3 is for a common type pulse transformer used in the blocking oscillator circuits.

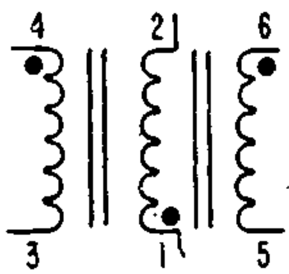


Figure 3

PULSE TRANSFORMER SCHEMATIC SYMBOL

NARRATIVE
LESSON 4

Blocking Oscillator

When you studied oscillators previously, you learned about oscillators which provide a sine-wave output. In Module 23, you learned about an oscillator which provided a square, or rectangular, output waveform. Recall that this type of oscillator was called a multivibrator.

Another type of oscillator which provides a non-sinusoidal output is the blocking oscillator. This type of oscillator, which is sometimes called a pulse repetition frequency generator, is used to trigger circuits in electronic equipment such as radar, computers, and television. It is used whenever pulses are required to trigger or control other circuits. The drawing shown in Figure 1 is a block diagram for a blocking oscillator, together with a typical output waveform.

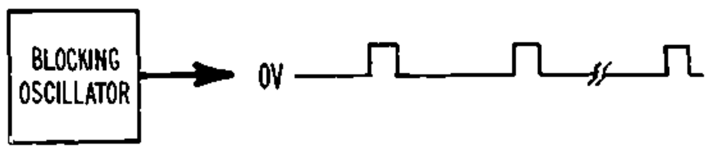


Figure 1

FREE RUNNING BLOCKING OSCILLATOR OUTPUT

The output pulse frequency and amplitude of a blocking oscillator will vary depending upon the particular equipment with which it is used. Blocking oscillator circuitry is capable of providing pulses that vary from 200 to 2000 pulses per second (PPS). The oscillator provides an output pulse which is very narrow. The on time, or pulse time, is relatively short; whereas the off, or rest time, is quite long.

There are a number of terms relating to blocking oscillators with which you should become familiar. These terms are also used with radar equipment. The terms, or concepts, are shown pictorially in Figure 2.

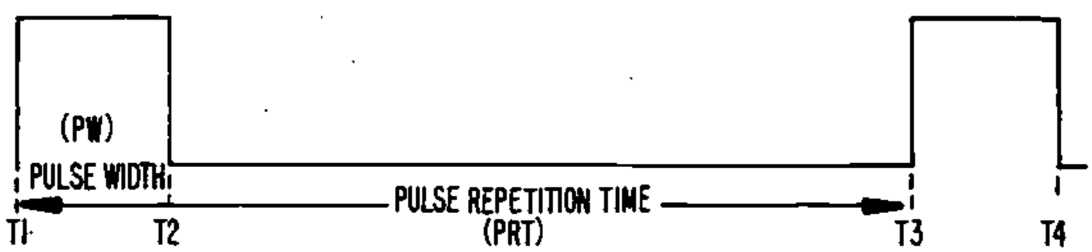


Figure 2

PULSE TERMINOLOGY

Figure 5 shows the schematic for a basic blocking oscillator circuit.

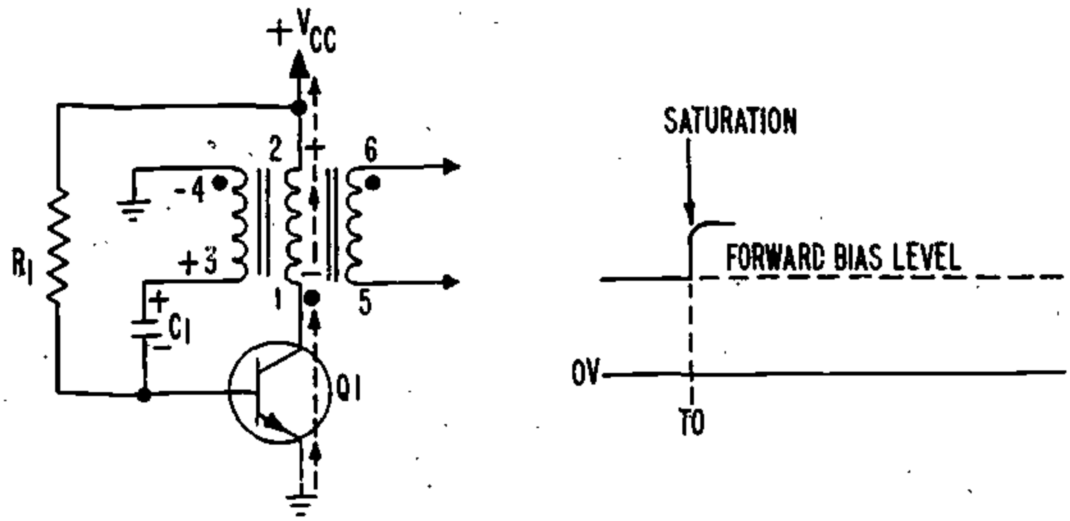


Figure 5

BLOCKING OSCILLATOR ACTION

Besides the schematic diagram, a waveform plotted against time is also shown. Showing the waveform in relation to time will help you understand the total operation of the blocking oscillator circuit.

Transistor Q1 is forward biased as the result of the action of R1. Because of this forward bias, when power is applied, the transistor conducts. This results in a smaller resistance between the emitter and collector of Q1. As a result, current flows from ground through Q1, the primary of transformer T1, to Vcc. Simultaneous with this there is a negative polarity at pin 1 and a positive polarity at pin 3 due to transformer action. This positive signal on the base of Q1 increases the transistor's forward bias and as a result the transistor conducts more. This action continues until the transistor or the pulse transformer reach the point of saturation. Because of its design, the transformer normally reaches the saturation point before the transistor does. The waveform shown to the right of the schematic in Figure 5 illustrates the saturation condition.

The pulse transformer has three windings. Besides a primary and secondary winding, this transformer has an additional winding which is called a tertiary winding. The word tertiary means third. The three windings of the transformer are wound on the same iron core in such a way that voltages are induced into both the secondary and teritary winding at the same time.

Notice the phasing dots shown on the schematic in Figure 3. In this case the voltage polarity at pins 1, 4, and 6 is identical. Besides having three windings, the pulse transformer is constructed in such a way that it saturates at low current levels. This means that once the transformer is saturated, any additional increase in current through the primary winding does not result in an increase in the secondary output voltage. This is a desirable and necessary condition for the operation of the blocking oscillator circuit.

Figure 4 shows schematics for a free-running blocking oscillator and a basic Armstrong oscillators.

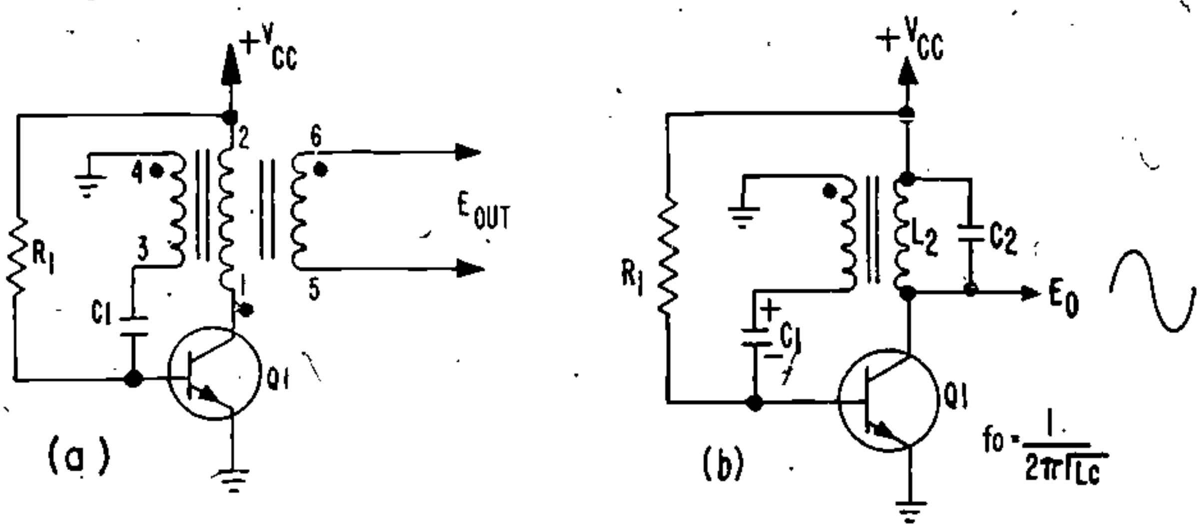


Figure 4

BLOCKING AND ARMSTRONG OSCILLATOR CIRCUITS

Study the schematics and notice the many similarities. The major difference between the two schematics is the frequency determining circuitry. While the Armstrong oscillator output frequency is determined by a tank circuit, the blocking oscillator uses an RC network to determine the output pulse frequency. This network is comprised of R1 and C1. The frequency of the oscillator may be changed by changing the values of R1 and C1. In the case of the blocking oscillator, regenerative feedback is provided by the inductive coupling of the pulse transformer, and the forward bias provided by R1 connected between Vcc and the base of the transistor Q1.

Figure 7 also shows the schematic for a blocking oscillator and a waveform. This waveform shows the effect the complete charge on capacitor C1 has on the transistor.

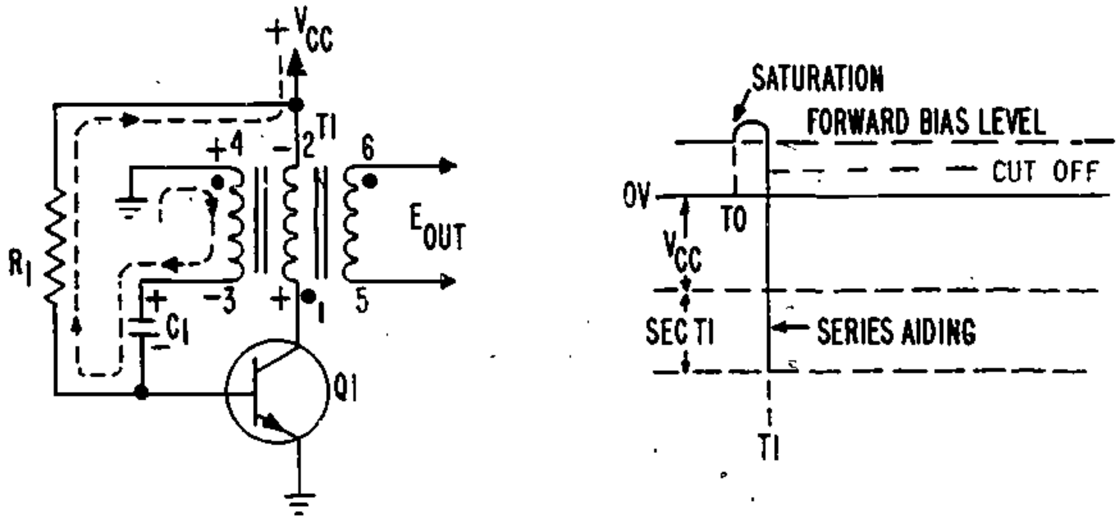


Figure 7

BLOCKING OSCILLATOR ACTION

Transistor Q1 is cut off when the charge on the capacitor C1 reaches maximum. At this time the capacitor charge is equal to the peak secondary voltage of the transformer across pins 3 and 4 . Q1 cuts off and the large stationary magnetic field of flux built around the primary winding of the transformer collapes.

From your study of inductors recall that an inductor opposes changes in current flow and therefore, in this particular case, the inductor attempts to keep current flowing in the same direction. As a result of this action, a voltage is induced across terminals 1 and 2 of the transformer with polarities as shown on the schematic. The induced voltage across terminals 1 and 2 of the transformer is coupled to the transformer's secondary (pins 3 and 4) as shown in the drawing. Study the drawing and notice that at this time the voltage across capacitor C1 and transformer pins 3 and 4 series aid and are <u>greater than</u> the voltage at Vcc. Transistor Q1 is now reverse biased and remains so until the magnetic field of the transformer primary winding collapses and capacitor C1 discharges.

As current flows through Q1, capacitor C1 charges to a voltage which is about equal to the peak secondary voltage of the pulse transformer T1.

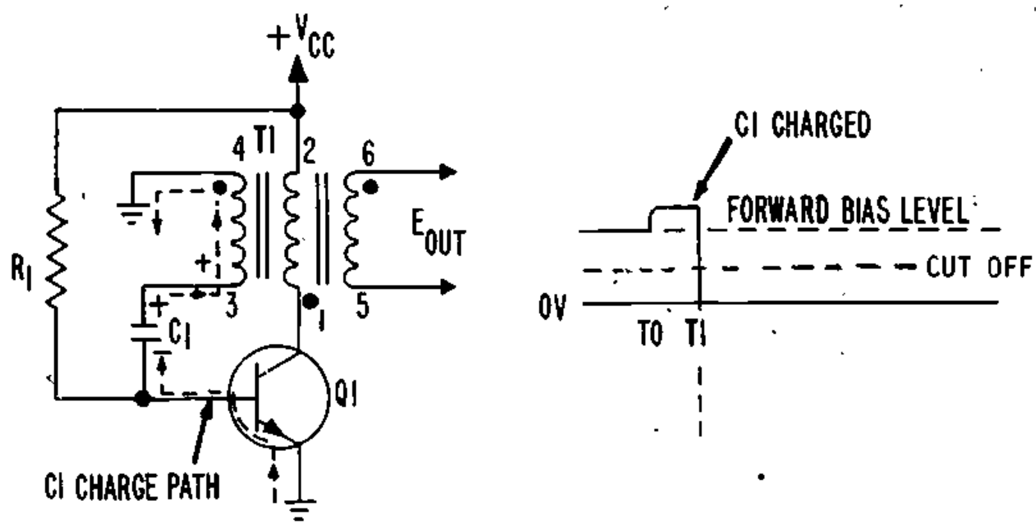


Figure 6

BLOCKING OSCILLATOR ACTION

Due to the heavy base-emitter forward bias on Q1, the junction resistance is very small. Thus, the RC charge time of C1 is short as shown by the waveform in Figure 6. The charge on capacitor CI approaches the peak secondary voltage of the transformer as current through Q1 decreases. When the capacitor is fully charged, the current between the base and the emitter of QI is reduced to a point where the transistor no longer conducts. At this time the transistor is cut off.

The waveforms shown in Figure 9 are included to help you understand the operation of the blocking oscillator circuit.

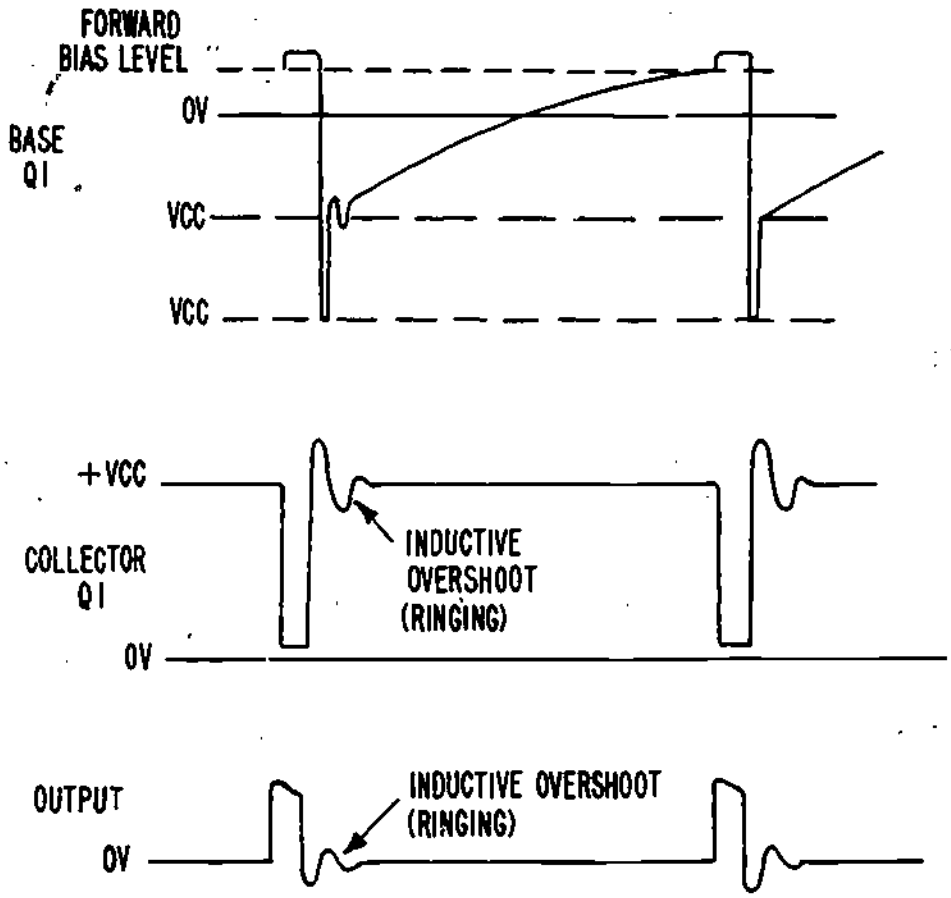


Figure 9

BLOCKING OSCILLATOR WAVEFORMS

Each waveform shows a potential in relation to zero volts. The top waveform shows the potential at the base of Q1, the middle waveform shows the collector potential, and the bottom waveform shows the tertiary output.

The waveform associated with the base of transistor Q1 shows circuit action when the transistor is forward biased and capacitor C1 is charging. Notice that the forward bias level is shown by a broken line. During this time the potential at Vcc is positive and greater than zero. This is shown by the collector waveform. When the capacitor is fully charged, it is series aided by the secondary of the transformer. At this time the negative voltage exceeds the positive voltage of Vcc and because the transistor is no longer forward biased, it stops conducting.

The schematic shown in Figure 8 shows the components which determine the length of time that the transistor is blocked. A waveform showing the discharge of capacitor C1 is also shown in the figure.

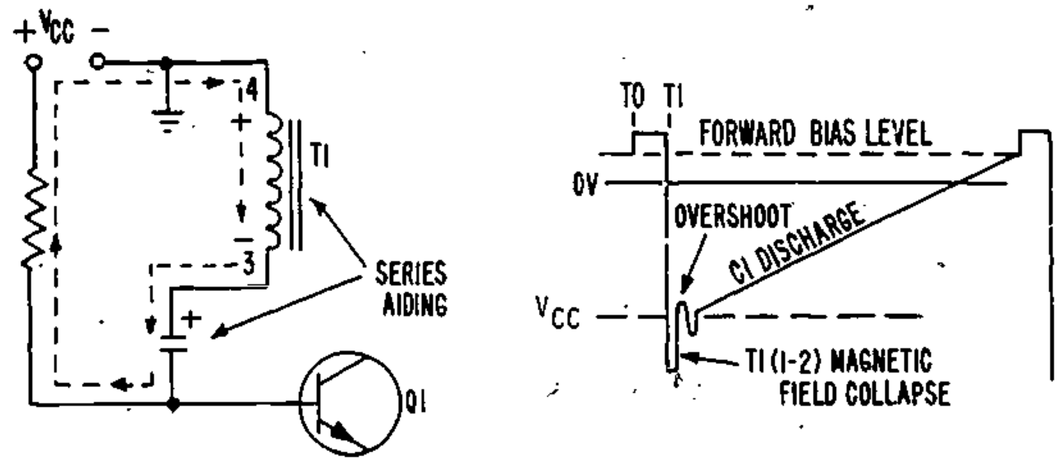


Figure 8

Q1 BLOCKING ACTION

The circuit is called the blocking oscillator because the transistor is cut off, or blocked, for a significant amount of time during each cycle of operation. When the magnetic field surrounding the transformer primary collapses, the voltage across terminals 3 and 4 drops to zero. The negative charge of the capacitor C1 causes the transistor to remain cut off. The capacitor discharges through resistor R1 to Vcc, then from ground through the transformer secondary winding (terminals 3 and 4) as indicated by the arrows. The discharge time of the capacitor is determined by the RC network comprised of R1 and C1. The concept of RC network charging and discharging was covered in Module 11.

Refer to the waveform shown on the right side of Figure 8 and notice the discharge curve associated with capacitor C1. As the capacitor discharges a negative potential is applied to the base of the transistor. Because of this potential, the transistor cannot conduct and is blocked.

Eventually, the capacitor discharges and a positive voltage (via Vcc and R1) is again applied to the base of the transistor. Because the transistor is again forward biased, it conducts, and the transformer action again produces regenerative feedback and oscillation resumes.

Another technique used for reducing the ringing, or overshoot, is to connect the diode across the output winding of the pulse transformer. This is also shown in Figure 10. In this case, the diode becomes forward biased whenever the output voltage at terminal 6 swings negative in relation to terminal 5. Because of the diode action, the output overshoot is limited, or clamped, to within a few tenths of a volt.

Waveforms shown in Figure 11 illustrate the output that results from the use of clamping diodes.

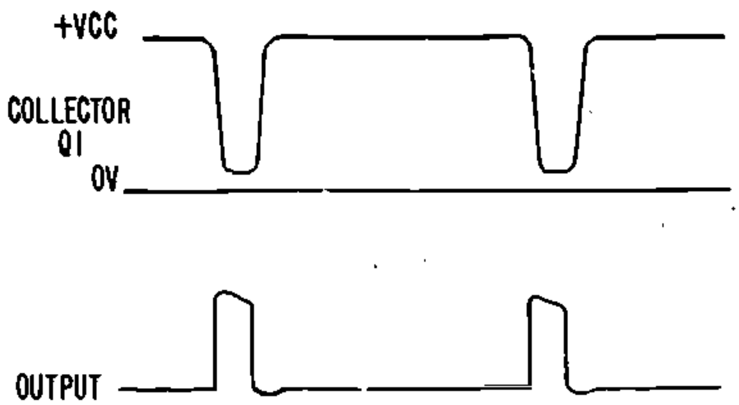


Figure 11

WAVEFORMS WITH CLAMPING DIODES

Look at the bottom waveform and notice that while the capacitor is discharging there is no output between terminals 5 and 6 the tertiary winding of the transformer. Examine the waveforms and notice the inductive overshoot or ringing effect. This undesirable output is the result of the rapid current change through the transformer windings which are basically inductances. The waveforms show that the stored energy of the magnetic field is not completely absorbed as the field collapses. The collapsing field causes an induced voltage of opposite polarity across the transformer windings. Because the damped oscillations may cause problems in other circuits associated with the blocking oscillator, several methods for eliminating the inductive overshoot or ringing have been developed.

A common method used for eliminating the inductive overshoot or ringing is to use clamping diodes as shown in Figure 10.

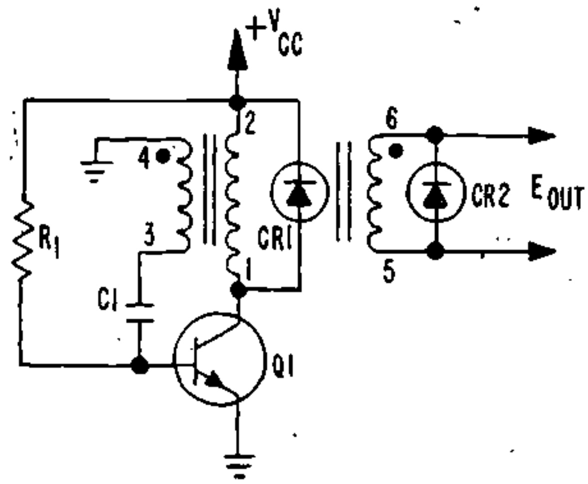


Figure 10

CLAMPING DIODES

CRI, the clamping diode, is placed directly across terminals 1 and 2 of the pulse transformer's primary. This diode becomes forward biased whenever QI cuts off and the voltage across terminal 1 and 2 of the transformer takes on the polarity as shown in the drawing. Because CRI has a relatively low resistance when forward biased, the inductive overshoot voltage and coil energy is quickly damped.

In this case, resistors R2, R3 and R4 are used as damping resistors. The resistors absorb some of the oscillation caused by the rapid collapse of the transformer's magnetic field. In some cases, resistors are used in conjunction with clamping diodes as indicated in previous frames. The circuit design and characteristics determine whether clamping diodes and resistive loads are used together or independently to accomplish the damping.

Figure 13 shows a schematic diagram for a slight variation of the basic blocking oscillator circuit. This schematic is for the Nida blocking oscillator which you will use and become familiar with when you complete the job program associated with this lesson.

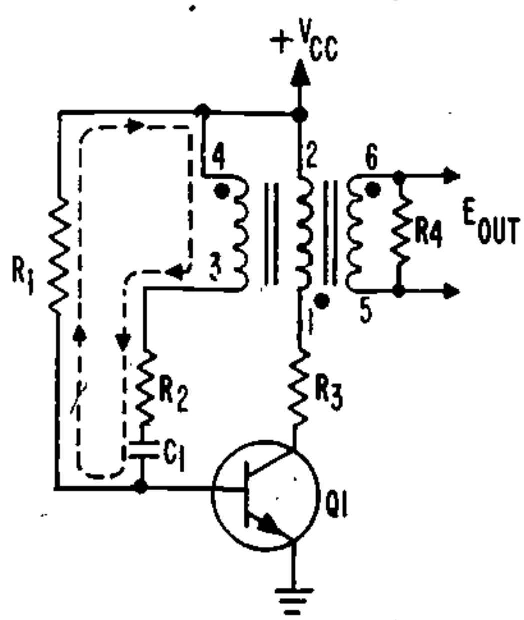


Figure 13

NIDA BLOCKING OSCILLATOR

The basic difference between this circuit and the blocking oscillator circuits presented in this lesson is that terminal 4 of the transformer T1 is returned to Vcc via ground. Such an arrangement removes the Vcc power source from the discharge path of the capacitor and improves the stability of the circuit. Other than this difference the operation of the NIDA blocking oscillator is essentially the same as the basic circuit. In this case, resistors R2, R3, and R4 function to dampen part of the undesirable oscillation of the transformer resulting from rapid current variation. One additional point concerning the blocking oscillator should be made. There are several variations of the basic circuit, for example, triggered, synchronized, and divider (count-down) versions. The basic distinction between these circuits and the basic circuit is that these variations require input triggers.

The ringing action of the transformer may also be reduced by using resistive loads, commonly called dampers. To accomplish this damping, small value resistors are placed in series or shunt with the transformer windings as shown in Figure 12.

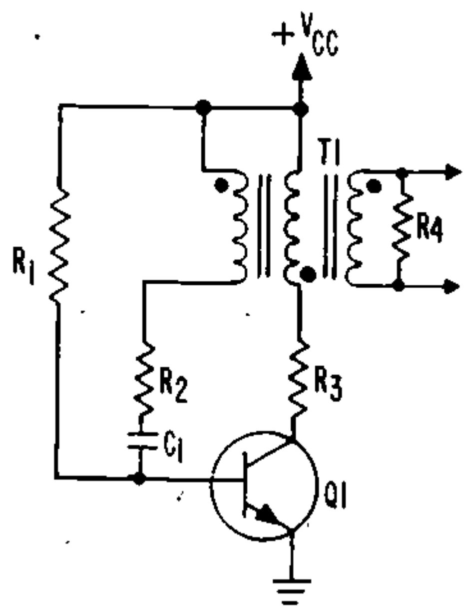


Figure 12

BLOCKING OSCILLATOR WITH DAMPING RESISTORS

203

MODULE THIRTY TWO

LESSON 5

CRYSTAL CONTROLLED OSCILLATORS

JULY 1980

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECLTY, PROCEED TO THE JOB PROGRAM. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON WITH WHICH YOU ARE HAVING DIFFICULTY. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULATION WITH THE LEARNING CENTER INSTRUCTOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

32.5.60.6 IDENTIFY techniques used to make small adjustments to the operating frequency of a crystal by selecting the correct statement from a choice of four. 100% accuracy is required.

BEFORE YOU START THIS LESSON, READ THE LESSON LEARNING OBJECTIVES AND PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

OVERVIEW
LESSON 5

Crystal Controlled Oscillators

In this lesson you will learn about the piezoelectric effect and its relation to crystals and crystal oscillators. You will study the use of a quartz crystal in series and parallel mode oscillator circuits. You will learn about methods for making small frequency changes in a crystal controlled oscillator circuit.

The learning objectives of this lesson are as follows

TERMINAL OBJECTIVE(S):

32.5.60 When the student completes this lesson, (s)he will be able to IDENTIFY the properties and characteristics of crystals, the component functions and modes of operation of Pierce and tickler coil crystal oscillator circuits, and techniques for adjusting the operating frequency of crystals by selecting statements from a choice of four. 100% accuracy is required.

ENABLING OBJECTIVES:

When the student completes this lesson, (s)he will be able to:

32.5.60.1 IDENTIFY the properties of crystals, including piezoelectric effect, and the functions crystals perform in an oscillator circuit by selecting the correct statement from a choice of four. 100% accuracy is required.

32.5.60.2 IDENTIFY the schematic symbol, AC equivalent circuit diagram, and electrical characteristics of a quartz crystal, both in isolation and when placed in a metal holder, by selecting the correct symbol diagram, or statement from a choice of four. 100% accuracy is required.

32.5.60.3 IDENTIFY the two modes of crystal oscillator circuit operation by selecting the correct statement from a choice of four. 100% accuracy is required.

32.5.60.4 IDENTIFY the circuit diagram, component functions, and mode of operation of a Pierce crystal oscillator circuit, given the schematic diagram, by selecting the correct statement from a choice of four. 100% accuracy is required.

32.5.60.5 IDENTIFY the circuit diagram, component functions, and mode of operation of a tickler coil crystal oscillator circuit, given the schematic diagram, by selecting the correct statement from a choice of four. 100% accuracy is required.

SUMMARY
LESSON 5

Crystal Controlled Oscillators

In any oscillator circuit, there is a method to select the desired operating output frequency. Crystal controlled oscillators provide extremely stable output frequencies.. The property which allows a crystal to oscillate is known as the "piezoelectric effect" which is shown in Figure 1.

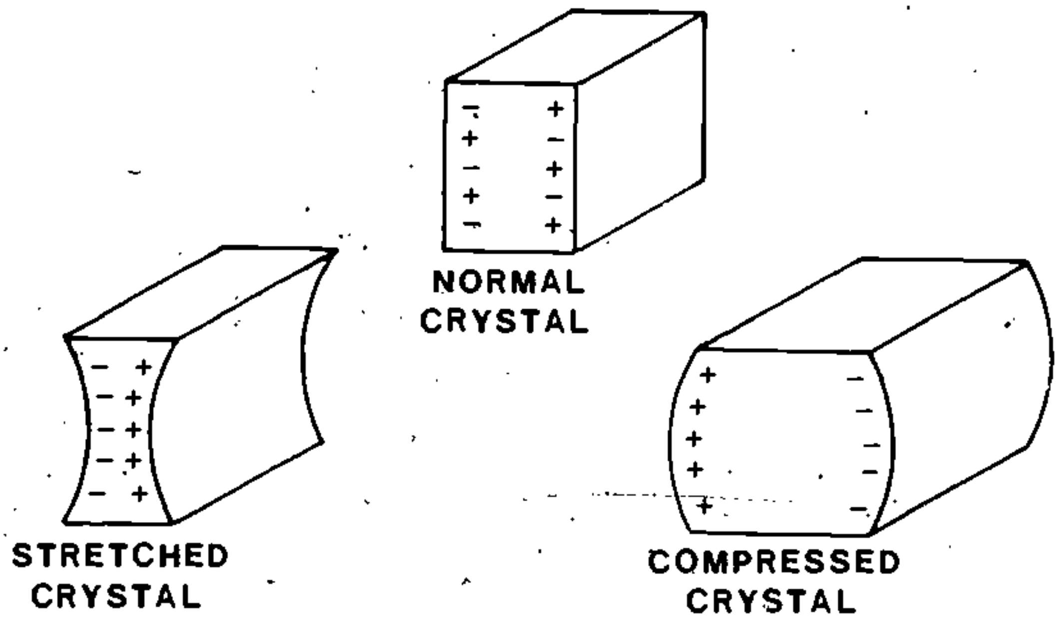


Figure 1

PIEZOELECTRIC EFFECT

As shown in the figure, tourmaline, Rochelle salt and quartz crystals will vibrate at their natural resonant frequencies when a voltage is applied. Conversely, vibrating crystals produce a voltage at a frequency which depends on the thickness of the crystal. The thinner a crystal is cut, the higher is both its natural resonant frequency and the AC voltage frequency it produces.

LIST OF STUDY RESOURCES
LESSON 5

Crystal Controlled Oscillators

To help you learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following study resources:

Written Lesson presentation in:

Module Booklet:

Summary
Programmed Instruction
Narrative

Student's Guide:

Summary
Progress Check

Additional Material(s):

Video Tape Audio/Visual Program "Crystal Oscillators"

Enrichment Material(s):

Base Electronics Vol. 1, NAVPERS 10087-C
Electronics Installation and Maintenance Book (EIMB) NAVSHIPS 0967-000-0120

YOU MAY USE ANY, OR ALL, RESOURCES LISTED ABOVE, INCLUDING THE LEARNING CENTER INSTRUCTION: HOWEVER, ALL MATERIALS LISTED ARE NOT NECESSARILY REQUIRED TO ACHIEVE LESSON OBJECTIVES. THE PROGRESS CHECK MAY BE TAKEN AT ANY TIME.

Electrically, a piece of unmounted quartz crystal is equivalent at a certain frequency to the series resonant circuit shown in Figure 4.

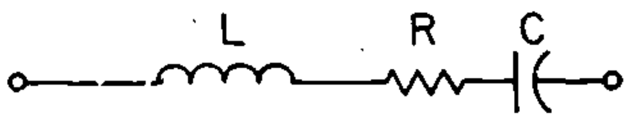


Figure 4

AC ELECTRICAL EQUIVALENT OF QUARTZ

When a crystal is mounted in a metallic holder, the electrodes attached to the crystal appear in parallel with the crystal as shown in Figure 5.

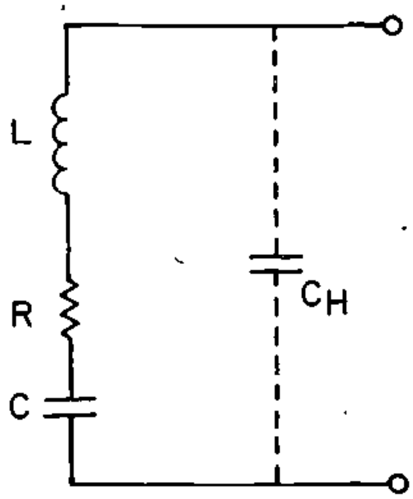
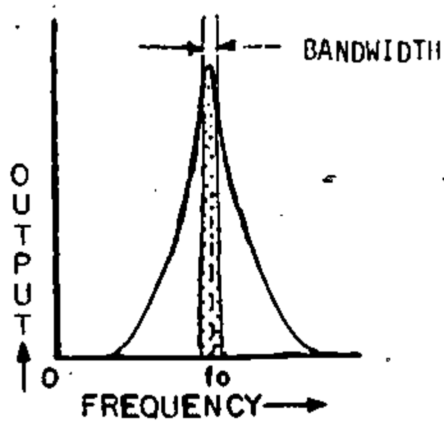


Figure 5

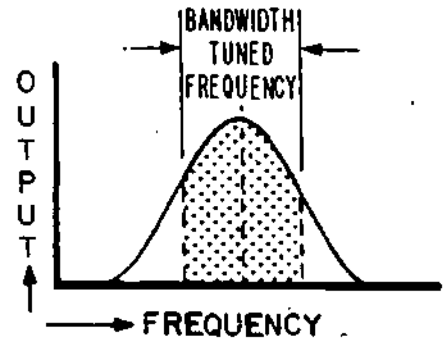
CRYSTAL EQUIVALENT CIRCUIT

A crystal oscillator operates at two distinct frequency points, or "modes". The series resonant mode is the natural resonant frequency of the crystal. The parallel mode (or anti-resonant mode) is caused by the parallel holder capacitance. The parallel mode occurs at a frequency slightly higher than that of the series resonant mode.

As in any oscillator, the AC voltage produced by a crystal oscillator will damp out unless regenerative (in-phase) feedback is received by the crystal. The crystal itself provides the regenerative feedback at the required frequency because of its narrow bandwidth and very high Q. Figure 2 compares the bandwidths of a crystal and an LC tank.



XTAL



LC

Figure 2

CRYSTAL VS LC TANK BANDWIDTH

Quartz is the most common material used in crystals. The schematic diagram for a crystal is shown in Figure 3.

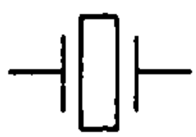


Figure 3

CRYSTAL SYMBOL

211

The Pierce crystal oscillator shown in Figure 7 is an example of an oscillator circuit which operates in the anti-resonant mode.

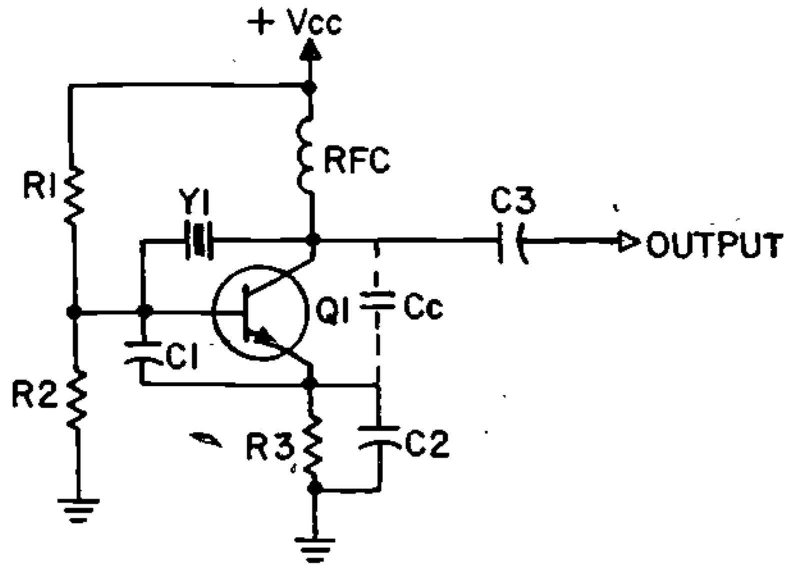


Figure 7

PIERCE XTAL OSCILLATOR

This oscillator is of the common Colpitts type, with the crystal in parallel with the voltage divider C1 and C_c. The impedance matching functions performed by the low reactance of C1 and the high reactance of C_c maintain the crystal's high Q and stable operating frequency. The ratio of the capacitive reactances of C1 and C_c determines the amount of regenerative feedback reaching the crystal.

The effect of the two modes of operation are shown in the frequency response diagram in Figure 6.

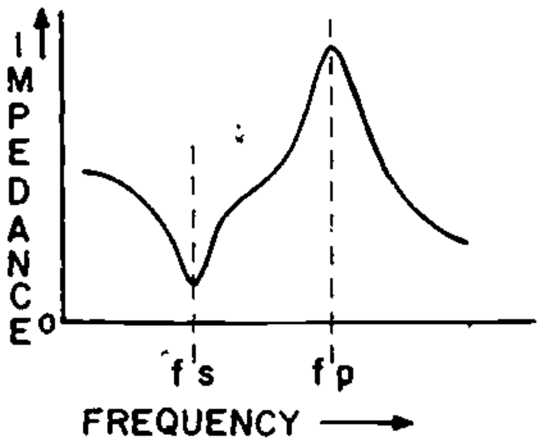


Figure 6

CRYSTAL IMPEDANCE VS FREQUENCY

As the frequency of a voltage applied to a crystal approaches the series resonant frequency (fs), the impedance of the crystal drops to a very low value. As the frequency of the applied voltage approaches the parallel resonant frequency (fp), the impedance increases sharply, thus exhibiting the characteristics of a parallel resonant tank.

In crystal oscillators, exact adjustments may need to be made to the crystal due to circuit requirements or crystal aging. Small adjustments to its operating frequency, called "pulling the crystal", can be made by placing a variable capacitor or inductor in series or in parallel with the crystal. A small-value trimmer capacitor is often used as shown by component C_4 in Figure 9.

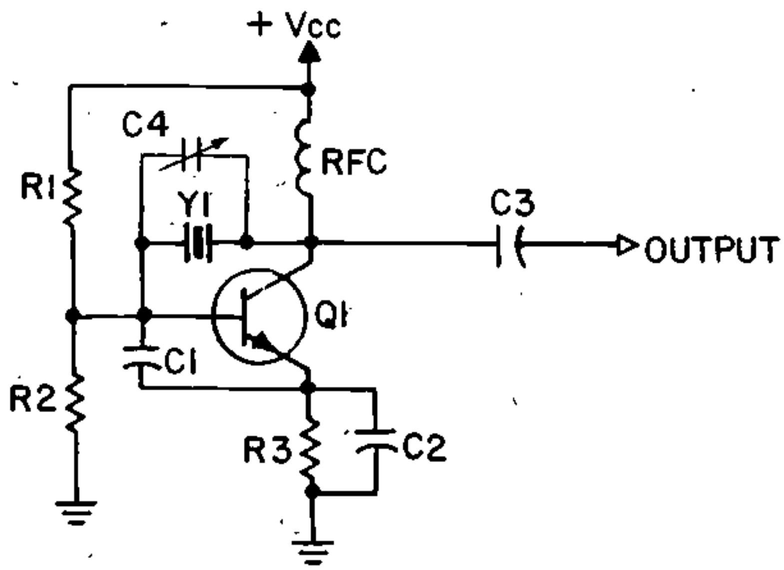


Figure 9

PIERCE CRYSTAL OSCILLATOR WITH TRIMMER

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, PROCEED TO THE NEXT LESSON. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH THE LEARNING CENTER INSTRUCTOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

The tickler coil (Armstrong) crystal oscillator shown in Figure 8 is an example of an oscillator circuit which operates in the series resonant mode.

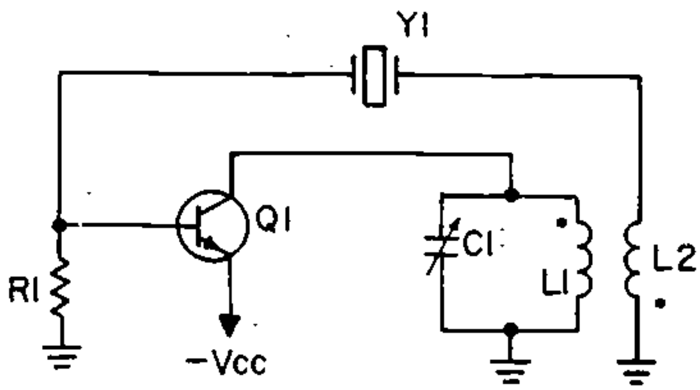


Figure 8

TICKLER COIL CRYSTAL OSCILLATOR

The L1C1 tank acts as the collector load, and is tuned to the crystal's resonant frequency. The crystal operates as a series resonant circuit to a single frequency which it passes to the base of Q1. The crystal filters out all other frequencies thus providing frequency stability.

215

PROGRAMMED INSTRUCTION
LESSON 5

Crystal Controlled Oscillators

TEST FRAMES ARE 5, 11, 17 AND 21. GO FIRST TO TEST FRAME 5 AND SEE IF YOU CAN ANSWER THE QUESTIONS THERE. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

1. All oscillators you have studied have had some method of frequency selection, or filtering to establish the operating output frequency. It may have been done by an LC tank circuit, by an RC phase shift network, or by some other filtering method. All such methods produce useful results in many circuit applications. However, these oscillators may not be stable enough when extreme frequency stability at high frequencies is important. These oscillators may have frequency limitations or frequency instability. One way to get the stability required is to use a crystal controlled oscillator XTAL oscillator).

Crystal oscillators have extremely good frequency

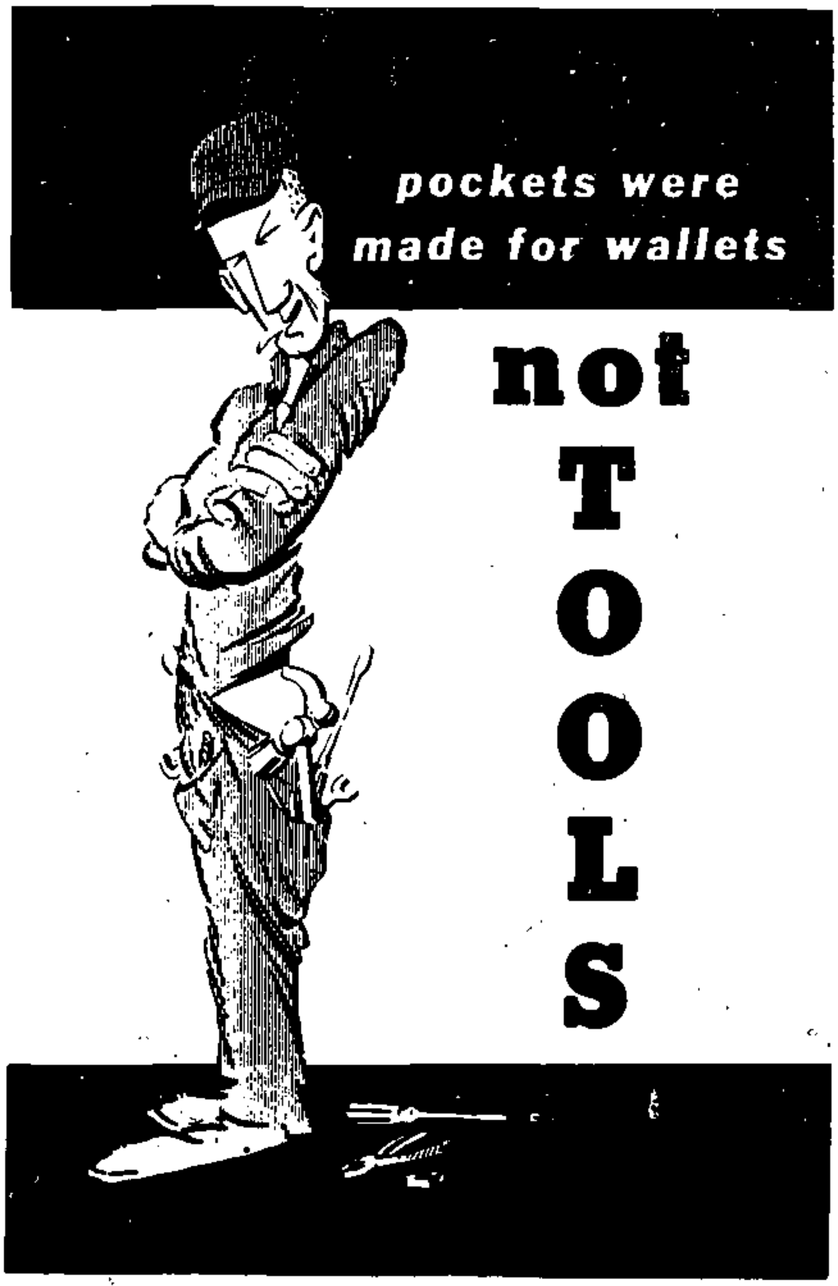
a. mixing
b. stability
c. phase shifting
d. modulating

---

b. stability

---

2. Tourmaline, rochelle salt, and quartz crystals have special properties that are useful in electrical circuits. What are these properties? Each of the crystals mentioned above has the ability to produce a voltage when pressure is applied to it. Conversely, each exhibits a mechanical strain when a voltage is applied to it. This property is called the "piezo electric effect" and is illustrated in Figure 1.


pockets were
made for wallets
not
TOOLS

3. As a voltage variation is applied to a crystal, it will vibrate at its natural resonant frequency. Generally, the natural resonant frequency is dependent on the crystal's thickness, as shown in Figure 2.

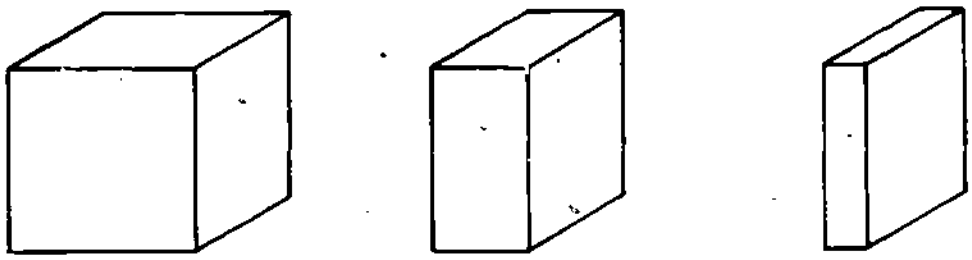


Figure 2

CRYSTAL FREQUENCY VS THICKNESS

As you can see, the thinner a crystal is cut, the higher (or faster) is the crystal's vibration frequency.

As a given crystal is cut thinner, the natural frequency or vibration produced by an applied voltage will (increase/remain the same/decrease).

---

increase

---

4. A crystal vibrating at its natural resonant frequency produces a voltage variation at that frequency. The voltage output from a vibrating crystal has characteristics similar to those of an LC tank circuit. If the crystal does not receive regenerative (in-phase) feedback, it will produce a damped wave output as does the tank circuit. In order to use a crystal in an oscillator circuit, the AC signal that excites the crystal must occur at its natural frequency.

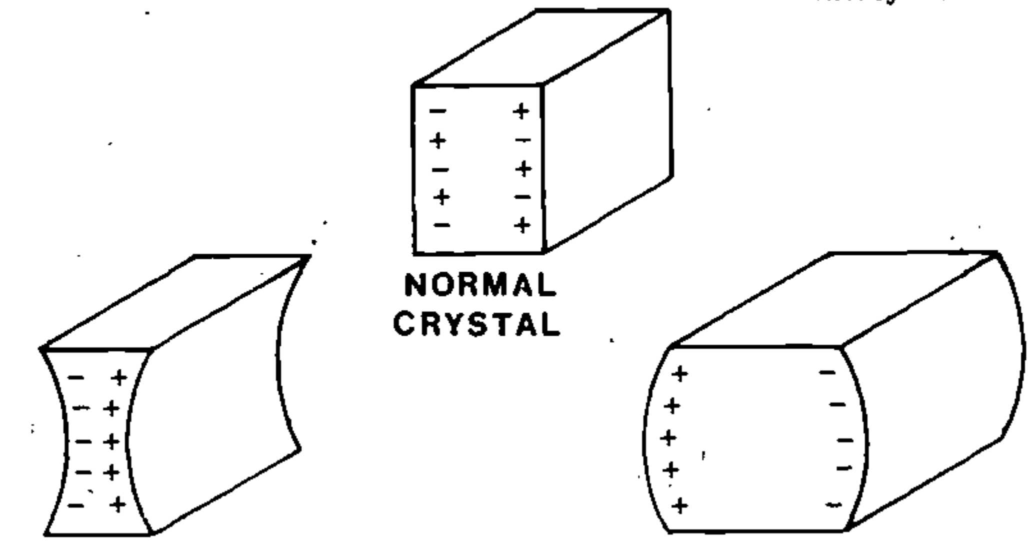


Figure 1

PIEZOELECTRIC EFFECT

In the normal crystal, notice that the static charges (shown by "+" and "-") are lying so that there is no measurable voltage across the crystal. However, in the pressure distorted crystals, a definite voltage can be felt on the crystals as pressure is applied in one direction or the other. The polarity of the voltage is determined by the type of crystal and by how the crystal is cut. This ability of the crystal to produce a voltage as pressure is applied is called the piezoelectric effect. The piezoelectric effect also causes the crystal to compress and stretch as a voltage is applied to it. Therefore, in a crystal, applied pressure causes a voltage, and applied voltage causes pressure distortions.

As a result of the piezoelectric effect, applying pressure on a crystal causes a ____________ across it, and applying a ____________________ to it causes pressure distortions in the crystal.

---

voltage, voltage

5. THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE PAGE FOLLOWING THE QUESTIONS.

1. Crystal oscillators are noted for having (better/poorer) frequency stability than other oscillators.

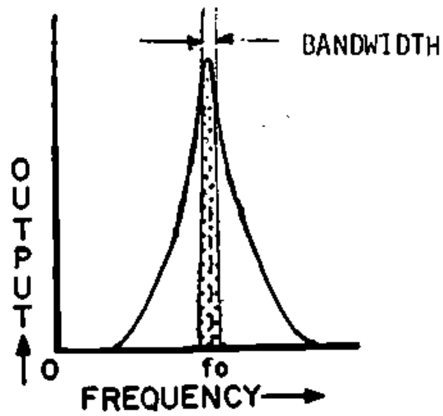
2. Crystals convert applied voltage into internal pressure changes, and convert pressure changes into voltages by using the ____________________ effect.

3. A thick crystal has a (higher/lower) natural resonant frequency than a thin crystal.

4. A crystal will function in an oscillator circuit if it receives in-phase, or ________________, feedback.

5. In a crystal controlled oscillator, frequency selection is performed by the ________________.

You have learned in your earlier studies that an amplifier will oscillate if it receives a regenerative signal. This oscillation will be anywhere within the frequency response of the amplifier. Therefore, some method of frequency selection, or filtering, is needed. In LC tank circuit oscillators, frequency selection used the LC tank circuit. In crystal controlled oscillators, the crystal acts as the frequency selection device. Because a crystal has a very high Q and a narrow bandwidth, crystal controlled oscillators are more stable than LC tank type or RC phase-shift oscillators. The bandwidth of a crystal and an LC tank are compared in Figure 3.



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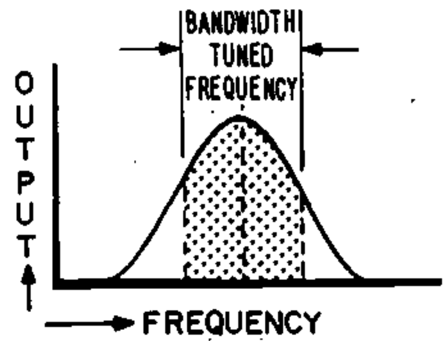


LC

Figure 3

CRYSTAL VS. LC TANK BANDWIDTH

In a crystal controlled oscillator, frequency selection is done by

a. an LC tank circuit
b. an RC network
c. the crystal
d. regenerative feedback

---

c. the crystal

1. better
2. piezoelectric
3. lower
4. regenerative
5. crystal

IF YOUR ANSWERS MATCH, GO ON TO TEST FRAME 11. OTHERWISE, GO BACK TO FRAME I AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 5 AGAIN.

6. Quartz is the most commonly used type of crystal. Quartz crystals are economical, durable, and easy to cut in their natural state.

All crystals are affected by heat or excessive temperatures. As the temperature changes, so does the physical size of the crystal. You already know that crystal size determines the natural frequency of the crystal. Therefore, it is easy to see that a stable crystal oscillator requires a stable temperature environment. In many crystal oscillators, the crystal itself is placed in a temperature-controlled device called an oven. In other crystal oscillator circuits, the components used may be temperature compensated.

Temperature changes (affect/do not affect) the natural frequency of a crystal.

---

affect

---

7. The schematic symbol for a crystal is shown in Figure 4.

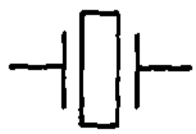
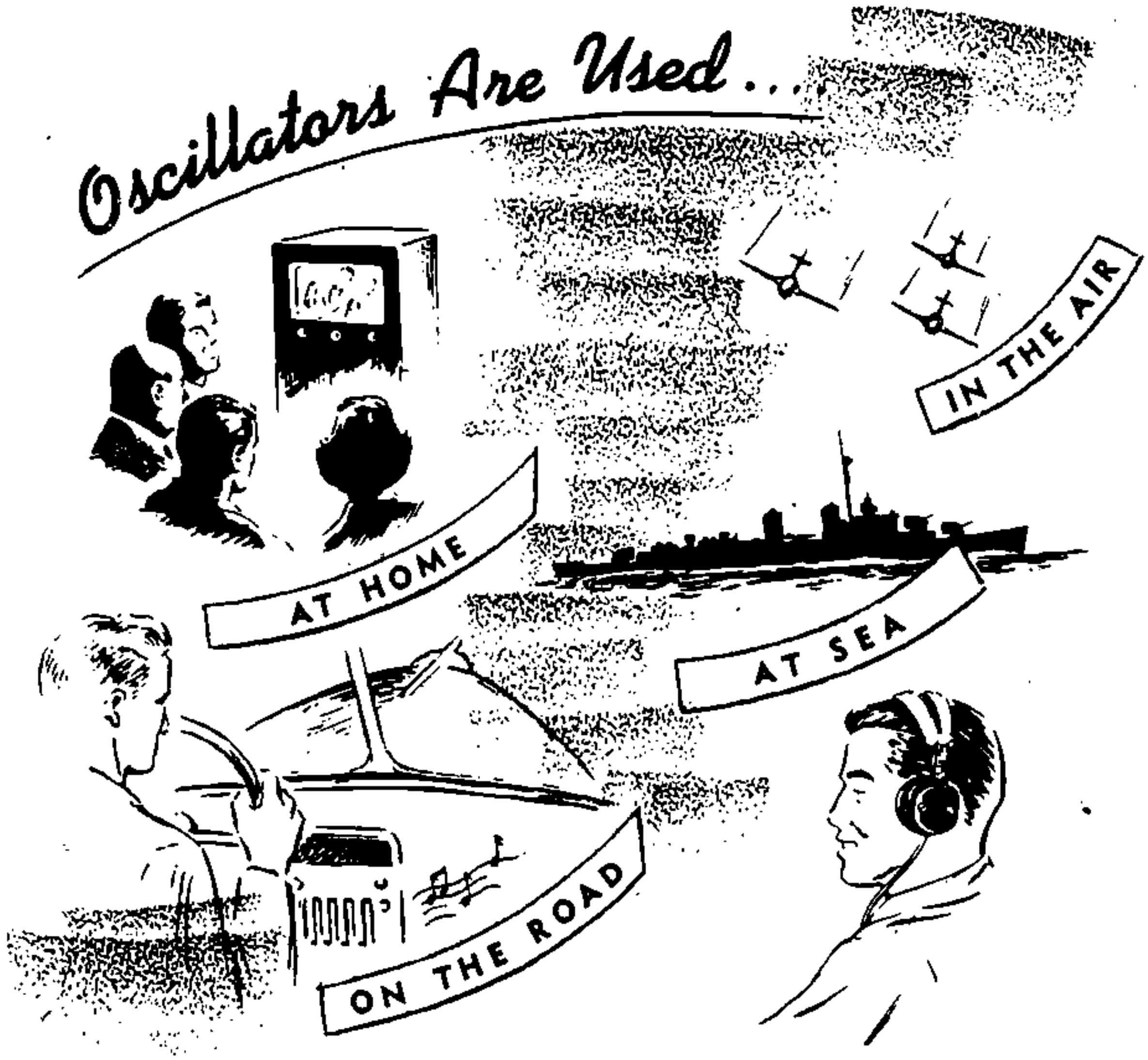


Figure 4

CRYSTAL SYMBOL

As you can see, the symbol is descriptive of the device, which basically is a piece of quartz between two metallic plates.



223

8. The electrical equivalent of a piece of quartz crystal is a series resonant circuit as shown in Figure 6.

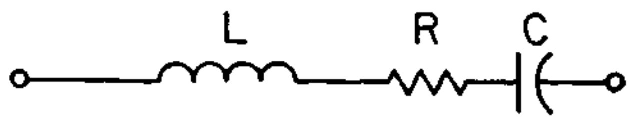


Figure 6

ELECTRICAL EQUIVALENT OF QUARTZ

As you remember from your study of resonance, a series resonant circuit has a characteristic low impedance equal to the resistance of R. (XL = XC and oppose each other.)

Since any two parallel metallic surfaces have capacitance between them, the electrodes attached to the crystal act as the plates of a capacitor. Therefore, the actual equivalent circuit of a crystal in a metal holder is as shown in Figure 7.

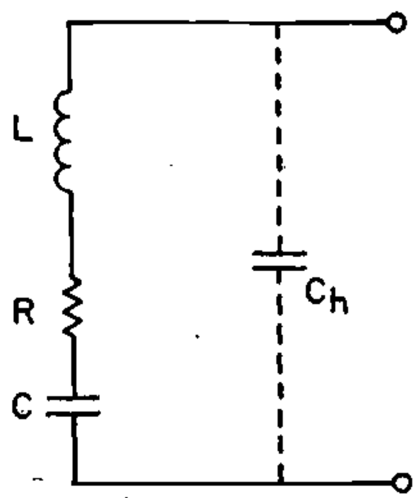


Figure 7

CRYSTAL EQUIVALENT CIRCUIT

In a circuit, the piece of quartz must be physically held rigid. It must also have metallic-plated electrodes attached to it for the application of an AC voltage. In Figure 5, a quartz crystal is shown mounted in a holder which provides these features.

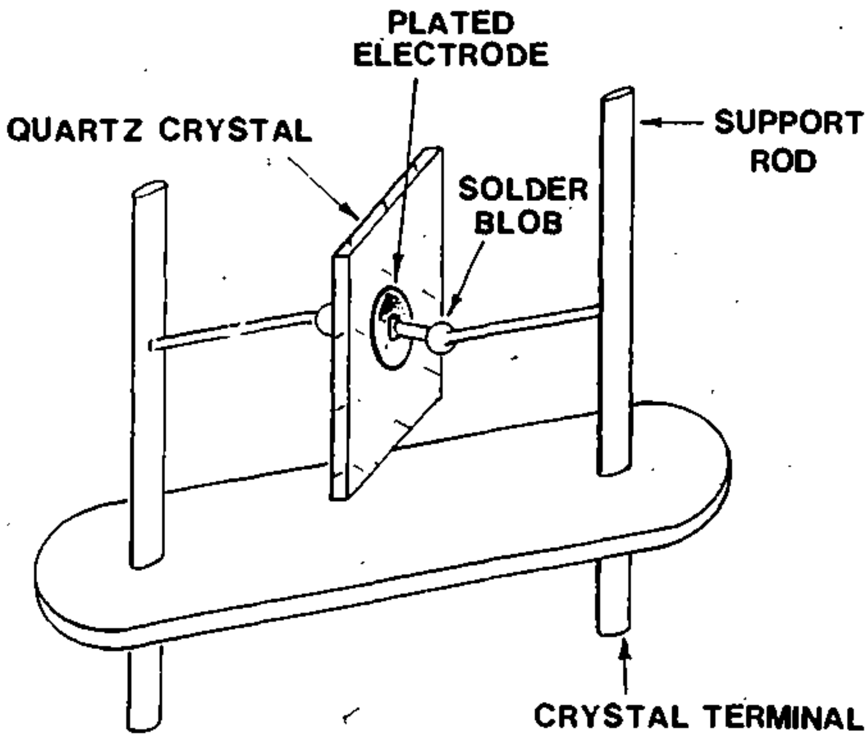


Figure 5

CRYSTAL MOUNTED IN HOLDER

A quartz crystal is mounted with metallic ________________ attached to it for the application of an AC signal.

---

electrodes

10. Lets conduct a simple experiment on paper to see how a crystal operates in the series resonant and parallel modes. Figure 8 shows a simple test circuit set-up.

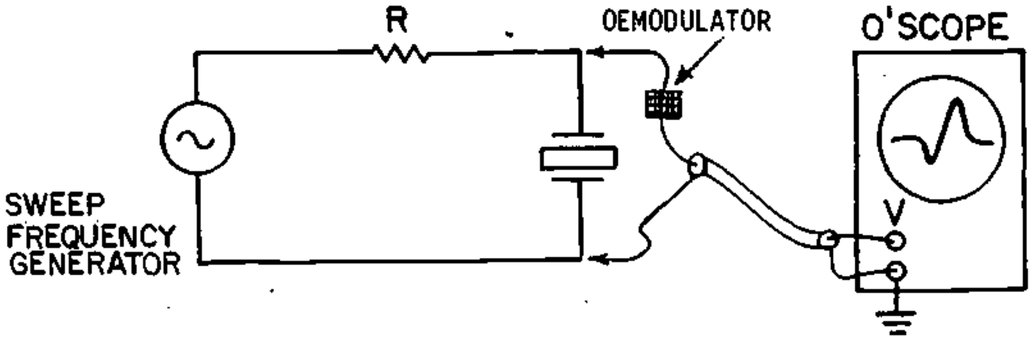


Figure 8

XTAL TEST CIRCUIT

This circuit consists of an RF sweep generator connected to a circuit consisting of a resistor in series with a crystal. As the generator frequency is swept from a point below the crystal's natural frequency to a point above it, the oscilloscope displays the pattern as shown in Figure 8.

This pattern is shown in greater detail in Figure 9.

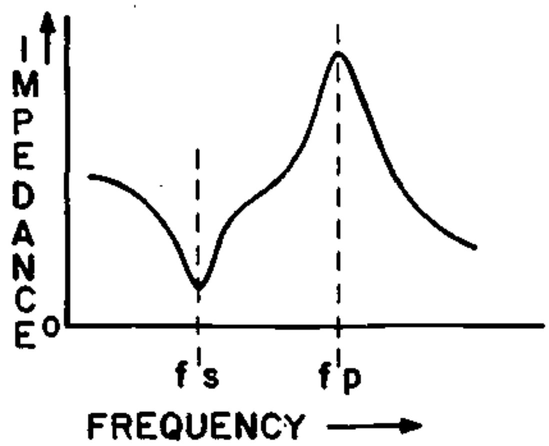


Figure 9

CRYSTAL IMPEDANCE VS FREQUENCY

The capacity labelled "C_h" is called the "holder capacitance" and appears in shunt with the crystal.

The equivalent circuit for a piece of quartz crystal is a (series/parallel) resonant circuit, and the metallic electrodes attached to the crystal act as a shunt (resistor/capacitor)?

---

series, capacitor

---

9. Quartz crystals have two different modes of operation caused by the electrical properties of the crystal itself and the crystal holder. The crystal itself forms the basic series resonant mode in which the crystal resonates at its natural frequency. The holder capacitance in parallel to the crystal forms the parallel mode, or anti-resonant mode. These two modes of operation do not occur at the same frequency. The parallel mode occurs at a slightly higher frequency than the series resonant mode (about .2% higher than the series resonant fo).

These two operating modes are very important in the operation of crystal oscillator circuits. One type of circuit will be designed to take advantage of the series resonant mode, and another type of circuit will take advantage of the parallel mode. The mode that is used will influence the oscillator operating frequency.

The parallel mode of operation for a crystal in an oscillator circuit occurs at a frequency which is slightly (lower/higher) than the series resonant mode.

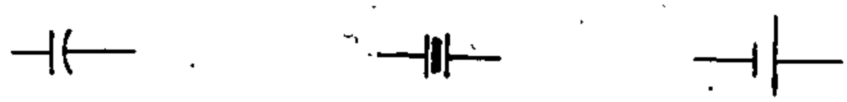
---

higher

(11.) THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE PAGE FOLLOWING THE QUESTIONS.

1. In a crystal oscillator, temperature compensation (is/is not) necessary to maintain frequency stability.

2. Which of the following symbols in Figure 10 below is the schematic symbol for a crystal?



a.   b.   c.

Figure 10

You can see that, as the frequency of the applied voltage approaches fs (series resonant frequency), the crystal's impedance becomes very low. As the generator frequency is moved slightly higher to fp (parallel resonant frequency), the crystal's impedance increases rapidly. At fp, the crystal appears as a parallel resonant tank with its characteristic high impedance.

An RF signal applied to a crystal at its series resonant frequency sees a (low/high) impedance, and an RF signal applied at the crystal's parallel resonant frequency sees a (low/high) impedance.

---

low, high

1. is
2. b.
3. a. series resonant circuit
4. c. shunt capacitor
5. lower
6. d. high impedance

IF YOUR ANSWERS MATCH, GO ON TO TEST FRAME 17. OTHERWISE, GO BACK TO FRAME 6 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 11 AGAIN.

12. Now let's look at the operation of some crystal oscillator circuits. A very common circuit is shown in Figure 11.

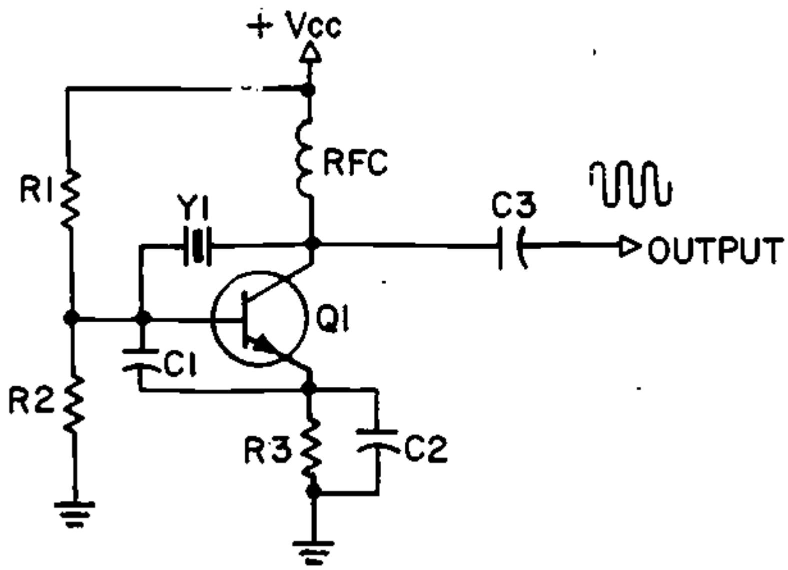


Figure 11

PIERCE XTAL OSCILLATOR

The Pierce oscillator in the figure is of the basic Colpitts type. When Colpitts oscillators are mentioned, you should immediately think of the capacitive voltage divider network across a tank coil, which is characteristic of this oscillator.

The Pierce oscillator in Figure 11 is of the basic ______________ type.

Colpitts

3. The electrical equivalent of a piece of quartz crystal is a

   a. series resonant circuit
   b. parallel resonant circuit
   c. capacitor
   d. diode

4. The electrodes attached to a crystal oscillator function electrically as a

   a. series capacitor
   b. series resistor
   c. shunt capacitor
   d. shunt resistor

5. The series resonant mode of operation for a crystal is at a slightly

   (lower/higher) frequency than is the parallel mode of operation.

6. A crystal that operates in the parallel mode, appears as a

   a. capacitive reactance
   b. low impedance
   c. impedance
   d. high impedance

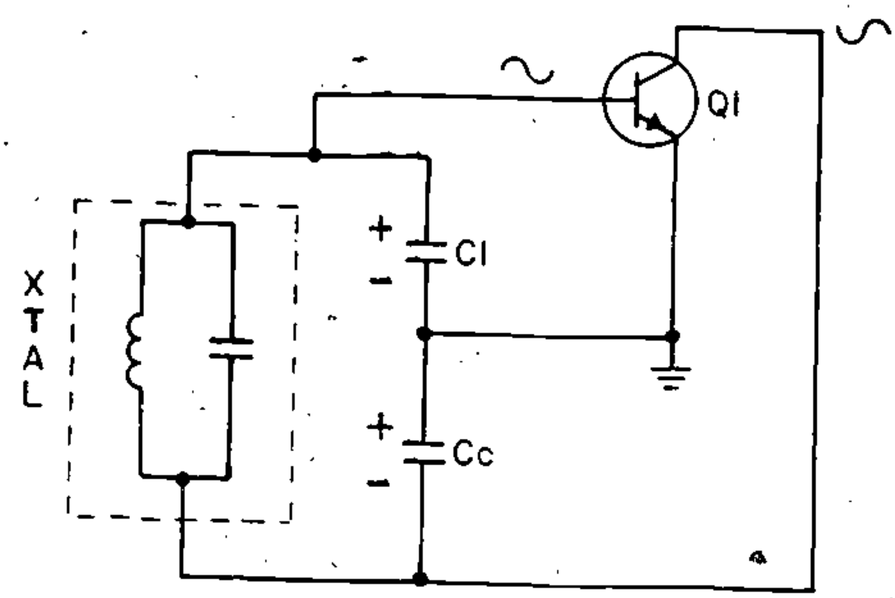


Figure 12

PIERCE OSCILLATOR - AC EQUIVALENT

13. Figure 12 shows the equivalent capacitive voltage divider circuit in a crystal controlled Pierce oscillator.

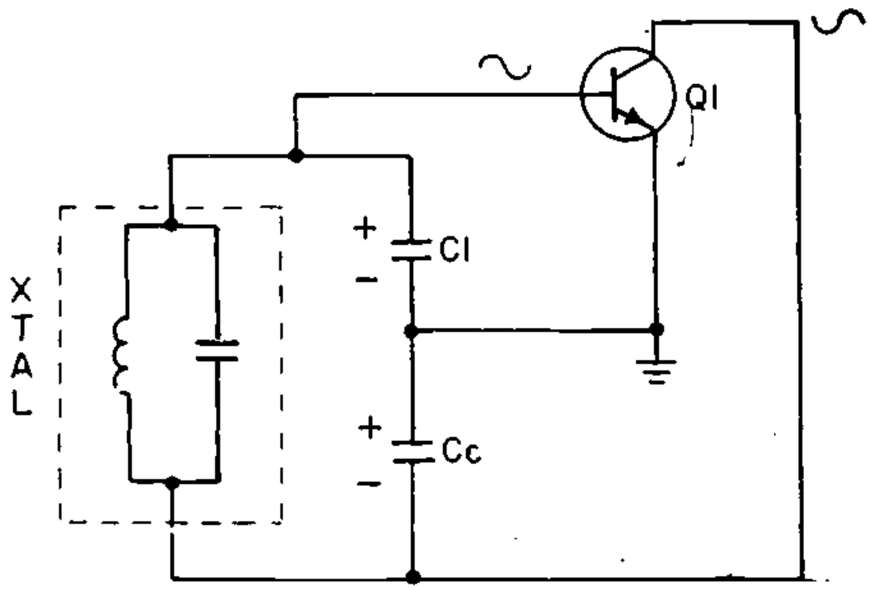


Figure 12

PIERCE OSCILLATOR - AC EQUIVALENT

The equivalent crystal circuit is within the dashed lines. Notice that the crystal is operating in the parallel mode. Capacitors C1 and Cc are in parallel with the crystal to form the capacitive voltage divider. Capacitor C1 is a real component. However, Cc represents the internal capacity of the transistor and the related output capacity between collector and emitter. Cc is usually a relatively small capacitance, less than one-tenth the value of C1. Therefore, the reactance of Cc is about ten times greater than the reactance of C1.

14. Let's continue our discussion of the AC equivalent Pierce oscillator circuit. Figure 13 repeats the circuit shown in Figure 12.

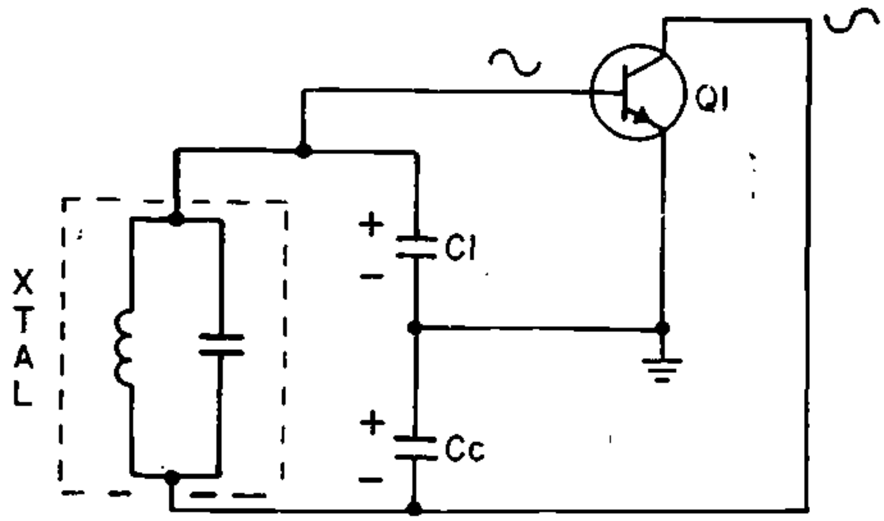


Figure 13

PIERCE OSCILLATOR - AC EQUIPMENT

In the figure, C1 and Cc determine the amount of regenerative feedback provided at the base of Q1, and indirectly to the crystal. Increasing the value of C1 would decrease its reactance, thus decreasing the feedback voltage applied to Q1. The amount of feedback reaching the crystal is a critical factor in crystal oscillators. Too little feedback results in weak, unstable, or even no oscillations. Too much feedback produces unstable and distorted outputs, and may even overdrive the crystal causing permanent damage.

Crystals are fragile devices, and should not be subjected to undue stress and strain. Electrically, this requires restriction of the drive voltage and current to specified limits. Physically, this requires that the crystal be handled with care. It should not be dropped or subjected to temperature extremes. When you solder crystals, you should make sure that the leads are heat-sinked to avoid possible internal crystal damage.

A careful study of this circuit arrangement shows that the tapped capacitive divider performs the very important impedance matching function required in bipolar (two-junction) transistor circuits. Recall from the earlier lesson on Q that placing parallel resistance across an LC tank tends to lower the tank's Q. Thus, in this circuit, the transistor base-emitter and emitter-collector resistances would tend to reduce the high Q of the crystal. However, this action is minimized by matching the low reactance of C1 to the low base-emitter resistance and the high reactance of Cc to the high emitter-collector resistance. This matching of impedance maintains the crystals high Q and stable operating frequency.

In Figure 12, the crystal's high Q and stable operating frequency are maintained due to the ____________ ______________ function performed by components ______________ and ______________.

---

impedance matching, C1 and Cc

235

(15.) The function of the components in the Pierce crystal oscillator, shown in Figure 14, now will be discussed.

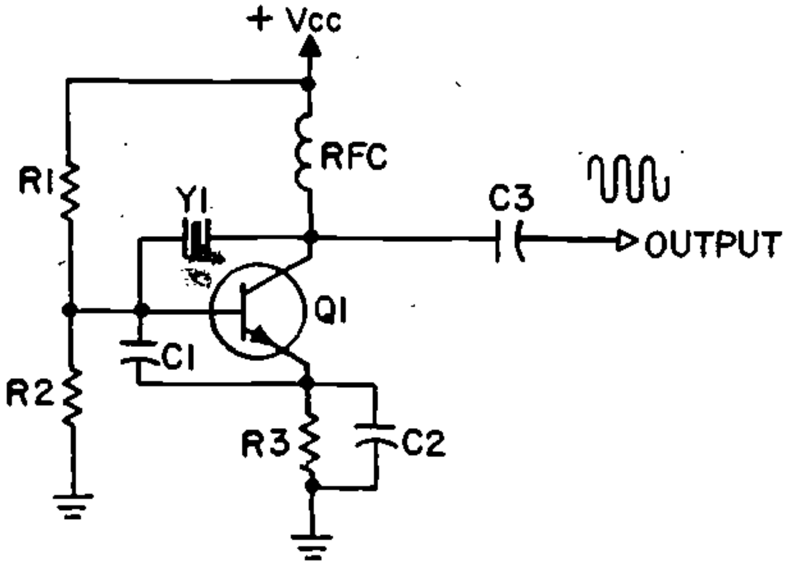


Figure 14

PIERCE XTAL OSCILLATOR

The circuit in the figure is composed of a basic common-emitter amplifier stage Q1 with related components R1, R2, R3, C2, and C3. The crystal oscillator components are Y1, C1, and the radio frequency choké (RFC). A resistor could replace the RFC. However, the RFC has the advantage of a low DC resistance with high AC reactance. Thus the RFC has less crystal loading than would a common resistor, and allows lower values of V_{CC} than a resistor.

In Figure 14, the three crystal oscillator components are ____________, ____________, and ____________.

Y1, C1, RFC (in any order)

Crystals may be damaged if

a. they receive too much regenerative feedback.

b. they receive too little regenerative feedback.

c. the drive voltage and current exceed specified limits.

d. both a and c above.

---

d. both a and c above.

(17.) THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE PAGE FOLLOWING THE QUESTIONS.

USE FIGURE 16 BELOW OF A CRYSTAL OSCILLATOR CIRCUIT TO ANSWER QUESTIONS 1 THROUGH 5.

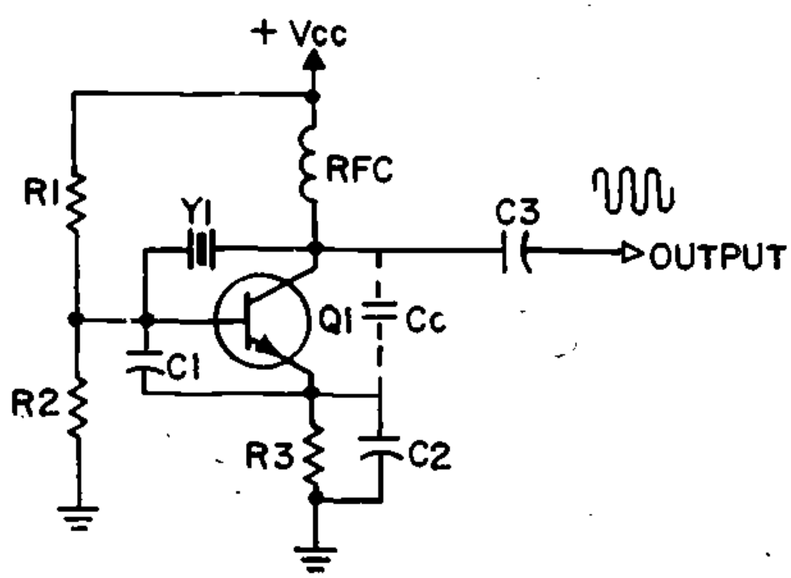


Figure 16

1. The figure is a circuit diagram for a ______________ crystal oscillator.
2. The crystal is operating in the (series resonant/parallel) mode.
3. The internal capacity of the transistor is represented by component ______________.
4. Regenerative feedback is determined by components Cc and __________.
5. Emitter stabilization is provided by components ________ and ________.

---

(16) The operation of the Pierce oscillator circuit shown in Figure 15 is not hard to understand.

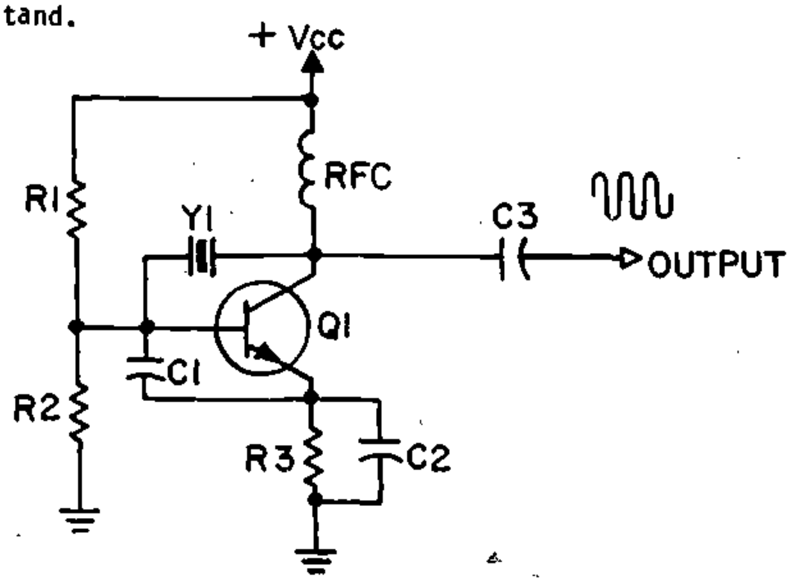


Figure 15

PIERCE XTAL OSCILLATOR

When power is applied to the circuit, current flows through R1 and R2 to V_{CC}. The base of Q1 becomes forward biased, which allows current to flow through Q1 from emitter to collector. The voltage stress across crystal Y1 develops internal crystal vibrations which produce an AC voltage on the base of Q1. This AC voltage is amplified and inverted 180° by Q1. The crystal then acts to couple the signal back to the base of Q1 with another 180° phase shift. This occurs at the parallel resonant frequency of the crystal. The result is a stable, high frequency output signal suitable for many applications in communications and electronics equipment where a signal with constant frequency and amplitude are required.

Many variations of this circuit are used. In one variation, a tuned tank is used as the collector load instead of the RFC. Other variations include the use of either PNP or NPN transistors.

In the Pierce crystal oscillator, the AC voltage produced by the crystal is fed back to the __________ of the transistor.

---

base

1. Pierce
2. parallel
3. Cc
4. C1
5. R1, R2

IF YOUR ANSWERS MATCH, GO ON TO TEST FRAME 21. OTHERWISE, GO BACK TO FRAME 12 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 17 AGAIN.

18. An example of a crystal oscillator circuit using the series mode of operation is shown in Figure 17.

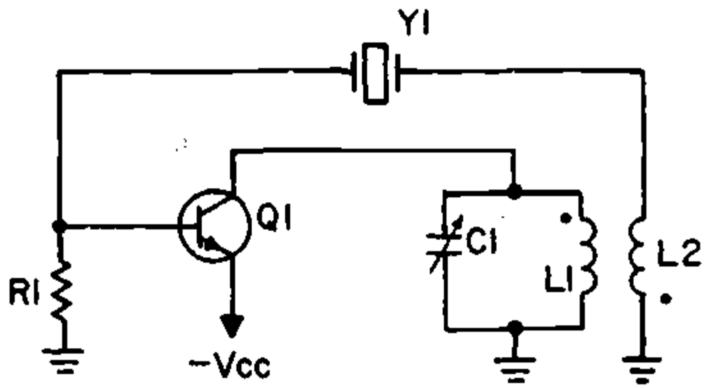
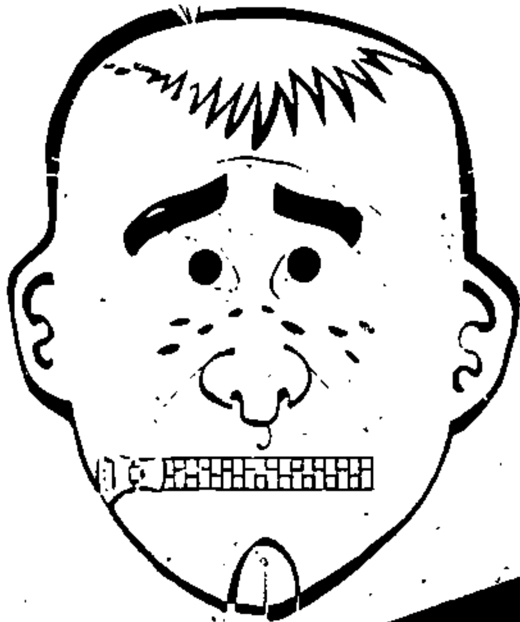


Figure 17

TICKLER COIL CRYSTAL OSCILLATOR

This circuit is a basic tickler coil (Armstrong) oscillator with a crystal inserted in series with the feedback path. Component R1, in relation with V_{CC}, provides forward bias for Q1. This enables the transistor to conduct and the oscillator to start. Tank circuit L1-C1 acts as the collector load for Q1, and is tuned to the crystal frequency. L2 provides 180° phase shift to the tank signal, and couples a small amount of this radio frequency energy to crystal Y1. The crystal operates as a series resonant circuit to a single frequency, which it passes to the base of Q1. Therefore, a total phase shift of 360° is achieved at the single frequency determined by Y1. The single frequency is the operating frequency of the oscillator, or fo. In this case, the crystal is acting to filter out all frequencies except the desired oscillating frequency.

GOT A SAFETY SUGGESTION?



Don't keep it to yourself!

U.S. Naval Safety Center,
NAS, Norfolk, Virginia 23511

C16 GS 26c

(20) Figure 18 shows an example of pulling the crystal in a Pierce crystal oscillator

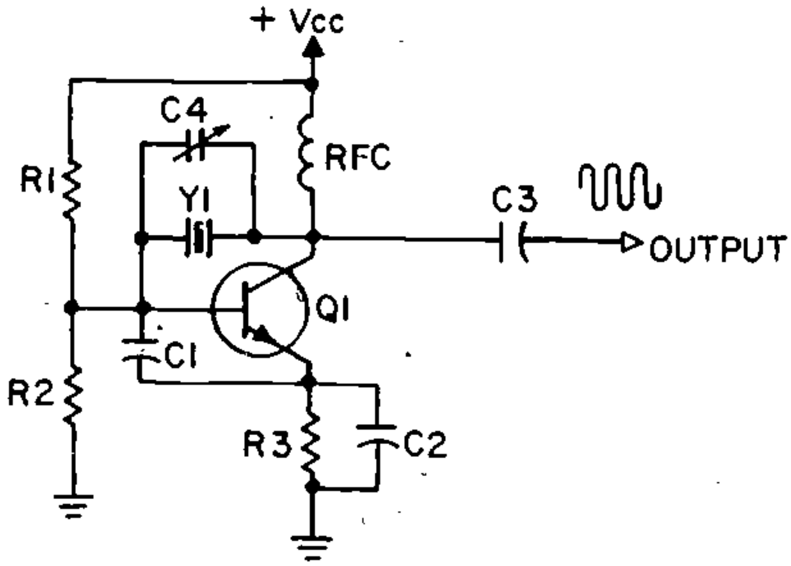


Figure 18

PIERCE CRYSTAL OSCILLATOR WITH TRIMMER

In the figure, component C4 is a small value trimmer capacitor which is placed in parallel across the crystal. This trimmer capacitor allows for precise adjustment of the output frequency to an exact value.

In Figure 18, the component which allows precise adjustment of the crystal's output frequency is ________________.

C4

In Figure 17, the total phase shift of 360° is provided by components

_______________ and _______________.

L2, Q1

---

19. Although the primary characteristic of crystal oscillators is their frequency stability, there is a need to change that frequency over a small range. Many applications require that fine adjustments be made to the operating frequency in order to make them more exact. Also, crystals do age causing changes in their structure which affect the resonant frequency.

The technique for making small adjustments to the operating frequency of a crystal is called pulling the crystal. Electrically, pulling a crystal requires that a variable reactance is placed either in series or in parallel with the crystal. The reactance may be either inductive or capacitive.

The technique of pulling a crystal allows for small adjustments to be made in the crystal's operating _______________.

---

frequency

213

(21.) THIS IS A TEST FRAME: COMPLETE THE TEST QUESTIONS, AND THEN COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE PAGE FOLLOWING THE QUESTIONS.

USE FIGURE 19 BELOW OF A CRYSTAL OSCILLATOR CIRCUIT TO ANSWER QUESTIONS 1 THROUGH 3.

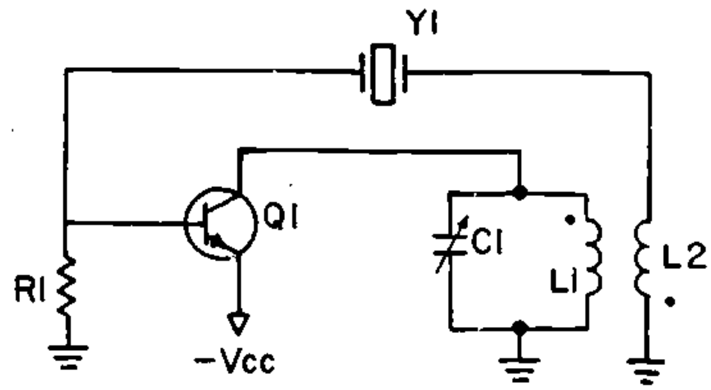
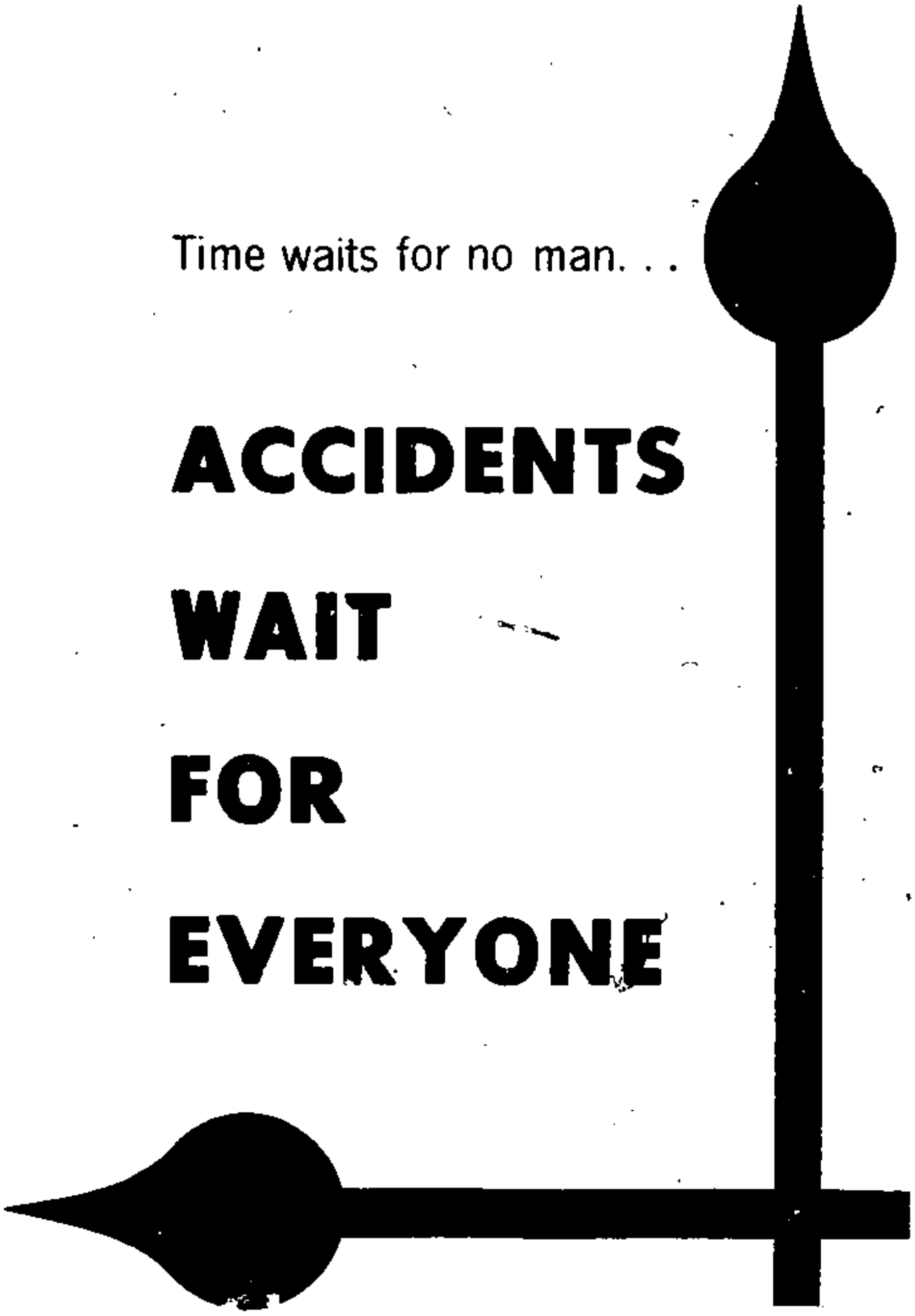


Figure 19

1. The oscillator in the figure is called a/an ____________________ crystal oscillator.
2. The crystal operates in the (series resonant/parallel) mode.
3. RF energy in the collector load tank circuit is phase shifted 180 degrees by component ________________ and another 180 degrees by ____________.

Time waits for no man. . .



ACCIDENTS WAIT FOR EVERYONE

COMPLACENCY KILLS!

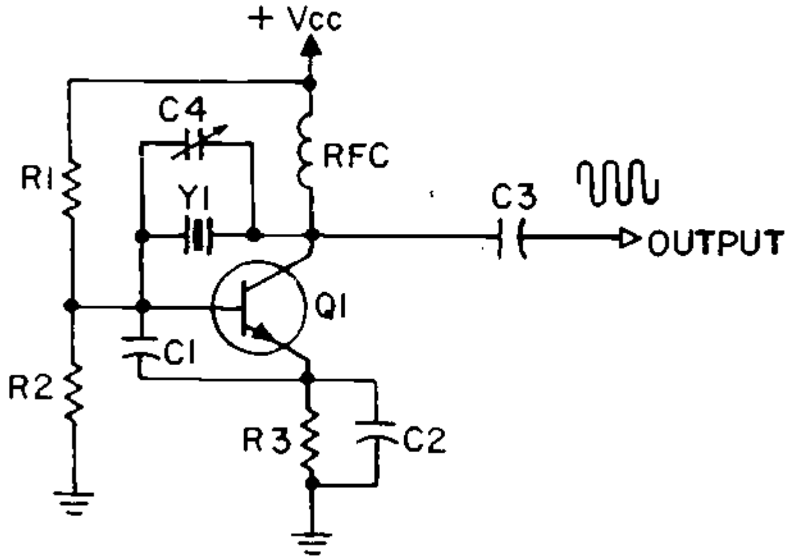
C32 GS-567
Contributed by AMHC K.M. Carpenter, VP-8

1. tickler coil (or Armstrong)
2. series resonant
3. L2 and Q1
4. b. allows for fine tuning of the crystal

IF YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU HAVE COMPLETED THE PROGRAMMED INSTRUCTION FOR LESSON 5, MODULE THIRTY TWO. OTHERWISE GO BACK TO FRAME 18 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 21 AGAIN.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, YOU MAY TAKE THE LESSON TEST. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN RESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OF INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH THE LEARNING CENTER INSTRUCTOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.

4. What is the function of component C4 in the crystal oscillator circuit shown below?



a. Provides the oscillator with a voltage divider network.

b. Allows for fine tuning of the crystal.

c. Impedance matches input and output signals.

d. Phase shifts the crystal output by 180 degrees.

247

NARRATIVE
LESSON 5

Crystal Controlled Oscillators

In any oscillator circuit, there is a method to select the desired operating output frequency. The methods of frequency selection previously studied--the LC tank circuit, RC phase-shift network, etc--produce useful results in many applications. However, when extreme stability at high frequencies is required, these methods often aren't good enough. Another type of oscillator, the crystal controlled (XTAL) oscillator, can provide this greater stability by using the properties of a crystal.

The property which allows a crystal to oscillate is known as the "piezoelectric effect." Tourmaline, Rochelle salt, and quartz crystals all exhibit this property, which is illustrated in Figure 1.

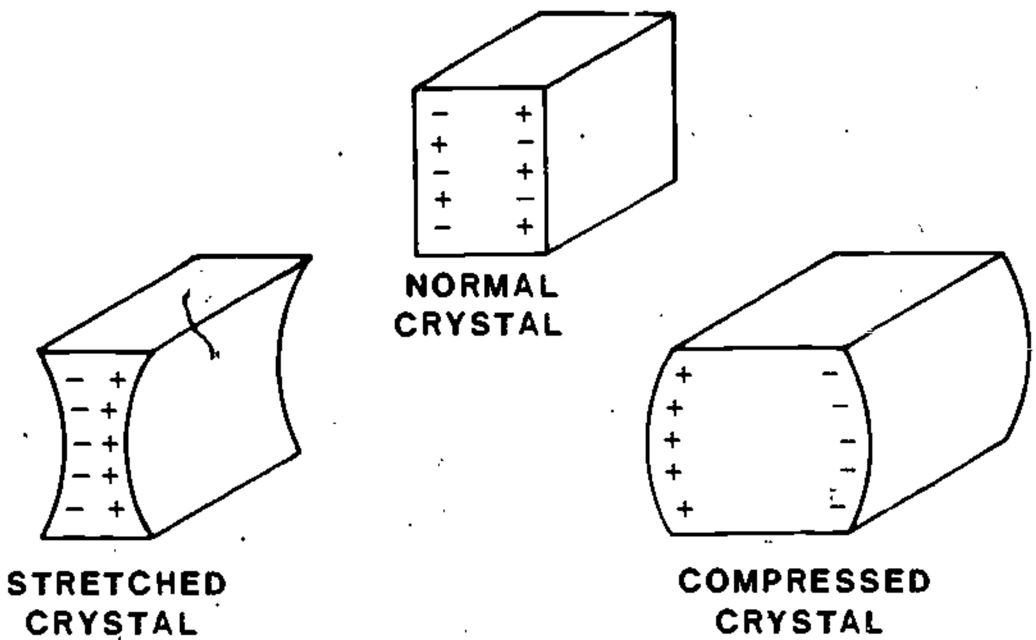


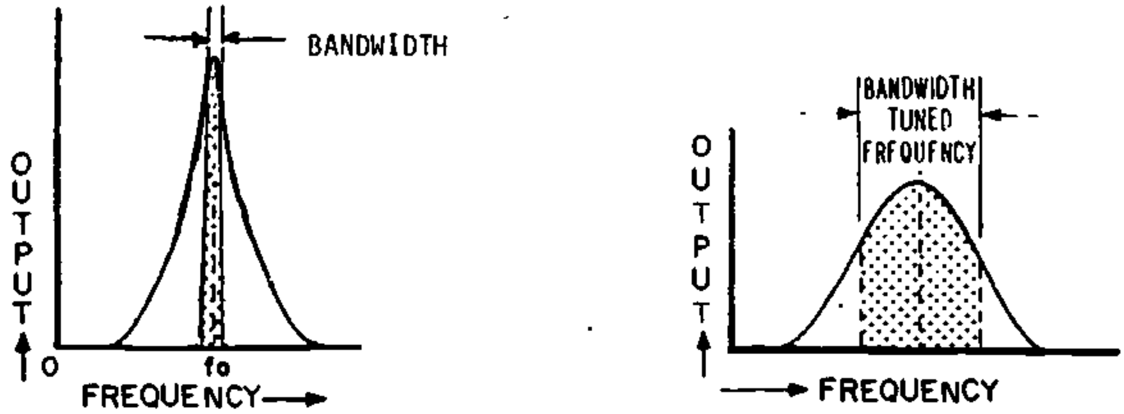
Figure 1

PIEZOELECTRIC EFFECT

In the normal unstressed crystal, the static charges (+ and -) are distributed so that no voltage is measurable across it. When the crystal is compressed or stretched by the application of pressure, the charges become polarized and a definite voltage can be felt. The polarity of the voltage depends on the type of crystal and the way it has been cut.

249

The bandwidth of a crystal and an LC tank are compared in Figure 3.



XTAL LC

Figure 3

CRYSTAL VS LC TANK BANDWIDTH

One important factor in the frequency stability of crystals is temperature. Changes in temperature can alter the shape and size of the crystal and thereby affect its frequency. For this reason, a stable crystal oscillator requires a stable temperature environment. Where the highest possible stability is required, the crystal may be placed in a temperature-controlled device called an oven. In less critical oscillator circuits, the use of temperature-compensated circuit components provides a stable enough environment.

Because it is economical, durable, and easy to cut in its natural state, quartz is the most common material used in crystals. Figure 4 shows the schematic symbol for a crystal.

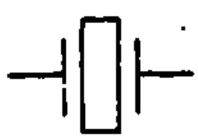


Figure 4

CRYSTAL SYMBOL

The piezoelectric effect also works in reverse. Just as applying pressure to a crystal causes a voltage to be produced, applying a voltage will cause the crystal to exhibit pressure distortions. The crystal will compress or stretch, depending on the polarity of the voltage applied. In addition, after the momentary application of a voltage, the crystal will alternate between compression and stretching, vibrating at a specific frequency. The frequency at which a given crystal vibrates is called its natural resonant frequency and is determined by the thickness(t) to which it has been cut, as Figure 2 illustrates.

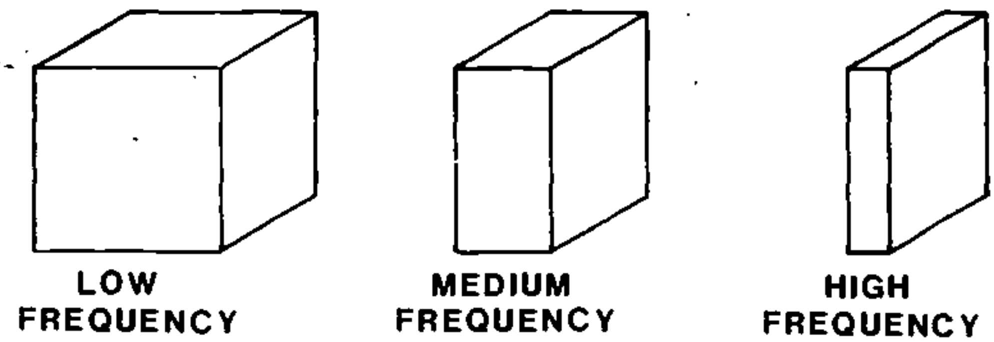


Figure 2

CRYSTAL FREQUENCY VS THICKNESS

A momentary application of voltage causes a crystal to vibrate at its natural resonant frequency. This vibration, and the sinusoidal (AC) voltage it produces, will damp out and cease unless the crystal receives regenerative (in-phase) feedback, like that required in an LC tank circuit. In other words, to keep the crystal vibrating at its natural resonant frequency, a regenerative AC feedback signal must be applied.

As stated in earlier lessons, if an amplifier receives a regenerative signal, it will oscillate. Because this oscillation can be anywhere within the frequency response of the amplifier, some method of frequency selection, or filtering, is needed. In the case of a crystal-controlled oscillator, the crystal itself acts as the frequency selecting device. Because its natural resonant frequency is very precise, a crystal has a narrow bandwidth and very high Q. Therefore, crystal controlled oscillators are more selective and more stable than LC tank type or RC phase-shift oscillators.

Electrically, a piece of quartz crystal, unmounted, is equivalent to the series resonant circuit shown in Figure 6.

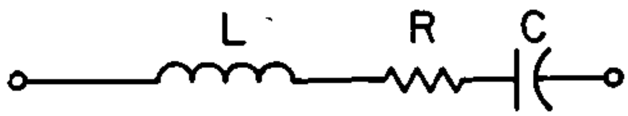


Figure 6

AC ELECTRICAL EQUIVALENT OF QUARTZ

Like the series resonant LC circuit, studied earlier, a crystal by itself, at a certain frequency, has a characteristic low impedance equal to the resistance of R. (XL and XC equal and oppose each other.) However, when the crystal is mounted in the metal holder, another factor is added. Since any two parallel metallic surfaces have capacitance between them, the electrodes attached to the crystal act like the plates in a capacitor. Therefore, the actual equivalent circuit of a crystal in its metal holder is as shown in Figure 7.

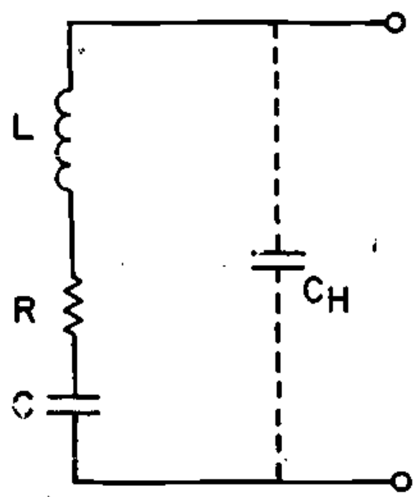


Figure 7

CRYSTAL EQUIVALENT CIRCUIT

The symbol is descriptive of the construction of a crystal: a piece of quartz between two metallic plates. The quartz must be held rigid so that it can vibrate and must have metallic electrodes attached so that voltage can be applied.

A quartz crystal is shown mounted in a holder in Figure 5.

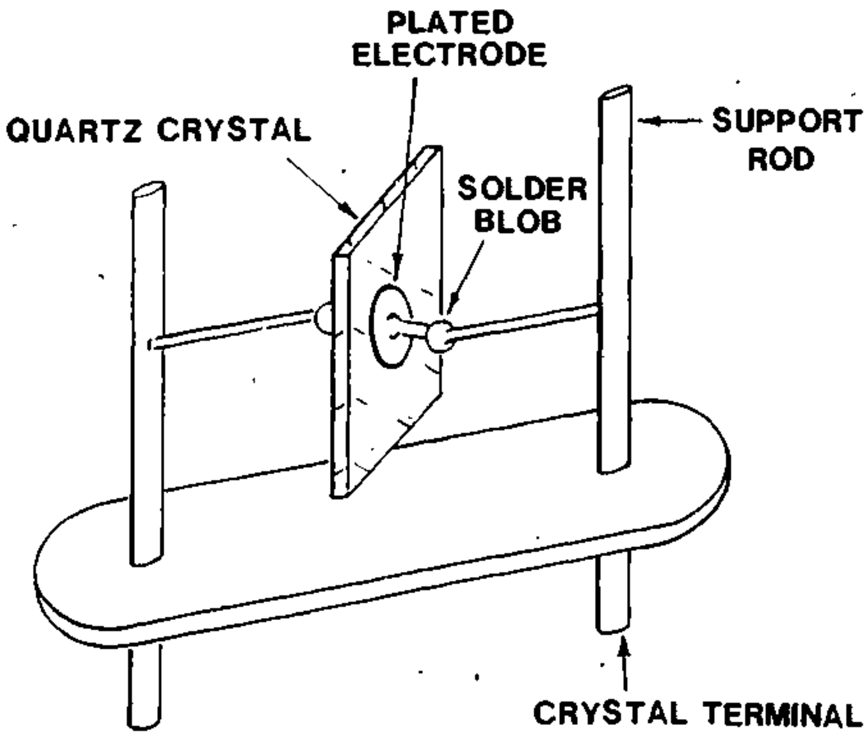


Figure 5

CRYSTAL MOUNTED IN HOLDER

This pattern is shown in greater detail in Figure 9.

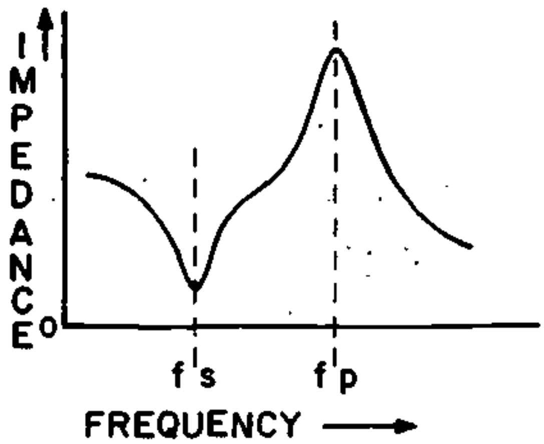


Figure 9

CRYSTAL IMPEDANCE VS FREQUENCY

As the frequency of the voltage applied to the crystal approaches its series resonant frquency (f_s), the impedance of the crystal drops to a very low value. Then, as the generator frequency sweeps slightly higher, approaching the parallel resonant frequency (f_p), the crystal's impedance increases sharply. At f_p, the crystal exhibits the high impedance which characterizes resonant tank.

As the figure shows, the holder capacitance (C_h) appears in shunt with the crystal. The addition of this capacitance makes it possible for the crystal to operate at two distinct frequency points, or "modes." The first of these, called the basic series resonant mode, is the natural resonant frequency of the crystal. The second, called the parallel resonant mode (or anti-resonant mode), is caused by the holder capacitance being in parallel with the crystal. The parallel resonant mode occurs at a frequency slightly higher than that of the series of resonant mode.

These two modes are the keys to understanding the operation of crystal oscillator circuits, which are designed to take advantage of either one mode or the other. A simple experiment on paper demonstrates how a crystal can act as either a series or parallel resonant circuit. The set-up for the experiment is shown in Figure 8.

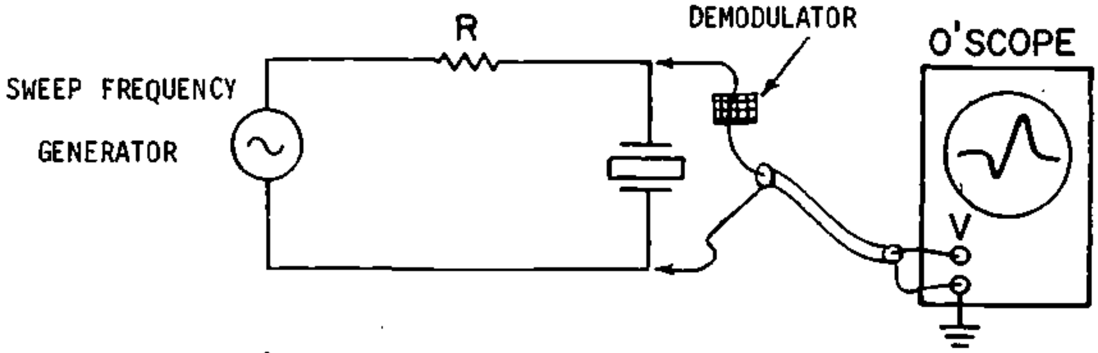


Figure 8

XTAL TEST CIRCUIT

This set-up consists of an RF sweep generator connected to a circuit in which a resistor has been placed in series with a crystal. As the generator frequency is swept from a point below the crystal's natural resonant frequency to a point above it, the oscilloscope displays the pattern as shown in the figure.

255

In order to better explain the operation of the Pierce oscillator, an equivalent version of the circuit is shown in Figure 11.

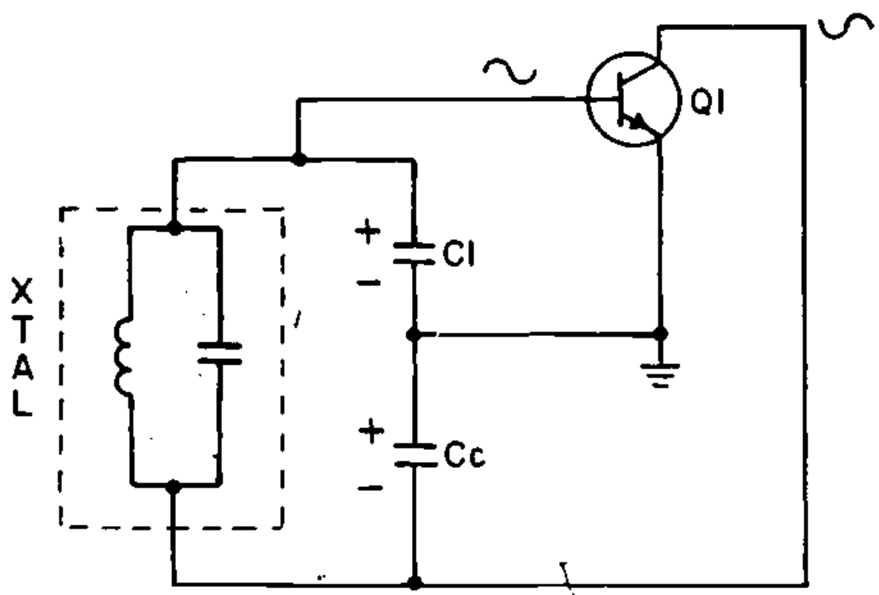


Figure 11

PIERCE OSCILLATOR--AC EQUIVALENT

The crystal, shown inside the dashed lines, operates in the parallel mode. C1 and C_C are in parallel with the crystal, forming the capacitive voltage divider. C1 is a real capacitor. C_C represents the internal capacity of Q1 and the associated capacity between its collector and emitter. C_C is a relatively small capacitance, usually less than one-tenth the value of C1. The reactance of C_C is therefore usually about 10 times greater than that of C1.

Because of the way the different values of C1 and C_C are arranged in the circuit, this tapped capacitive divider is able to perform the very important impedance matching function required in bipolar (2 junction) transistor circuits. Study Figure 11 carefully. Just as in an LC tank circuit, the transistor's base-emitter and emmitter-collector resistances will tend to reduce the high Q of the crystal. However, this action is minimized by matching the low reactance of C1 to the low base-emitter resistance, and matching the high reactance of C_C to the high emitter-collector resistance. This impedance matching maintains the crystal's high Q and stable operating frequency.

The first of two types of crystal oscillator circuits to be presented in this lesson, the Pierce oscillator, is shown in Figure 10.

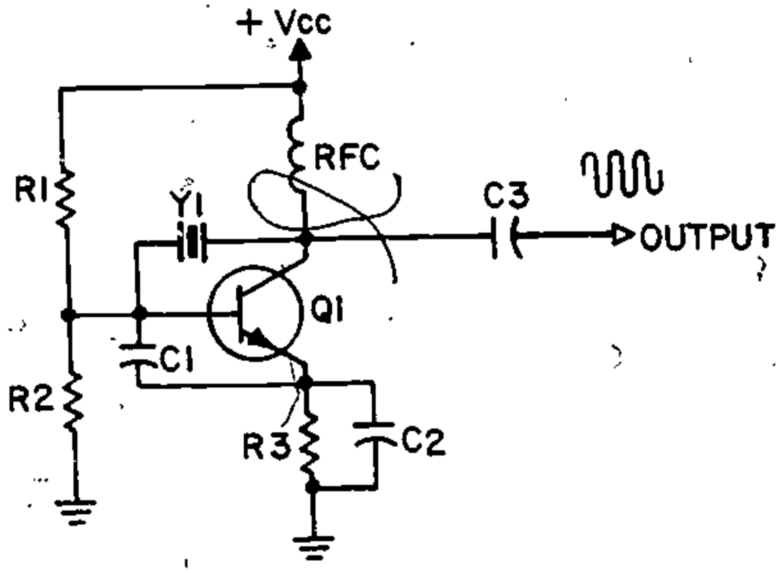


Figure 10

PIERCE XTAL OSCILLATOR

The Pierce oscillator shown is related to the very common Colpitts type. A capacitive voltage divider network across a tank coil is characteristic of this type of oscillator.

257

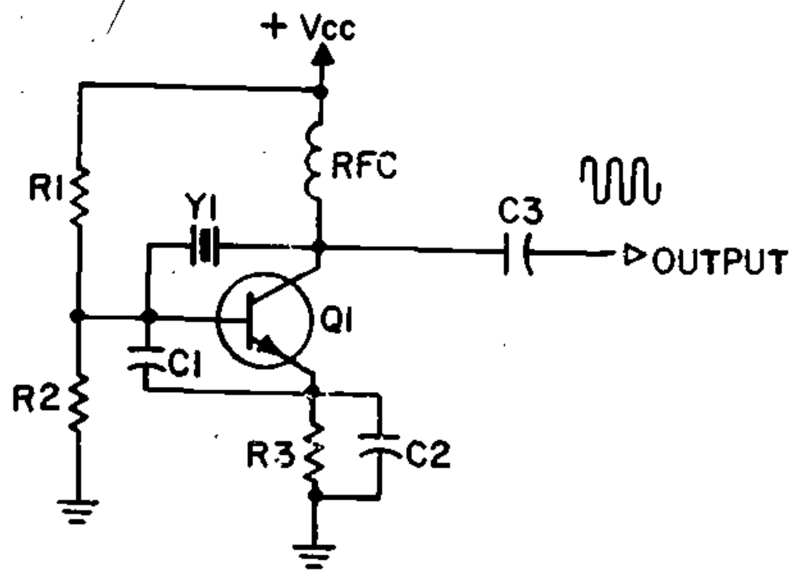


Figure 12

PIERCE XTAL OSCILLATOR

The circuit consists of a basic common-emitter amplifier stage (Q1 and related components R1, R2, R3, C2 and C3) with added crystal oscillator components Y1, C1, and the radio frequency choke (RFC). A resistor could replace the RFC. However, the RFC's low DC resistance and high AC reactance cause less crystal loading, and permit lower V_{CC} values than would be possible with a resistor.

R1 and R2 provide forward bias for Q1, while R3 and C2 provide emitter stabilization. C3 couples the sine wave oscillator signal to the next stage. C1, as shown above, provides the optimum feedback voltage to the base of Q1.

When power is applied, current flows through R1 and R2 to V_{CC}. The base of Q1 becomes forward biased, allowing current to flow through Q1 from emitter to collector. Voltage stress across crystal Y1 causes the crystal to vibrate, producing an AC voltage which is applied to the base of Q1. This voltage is amplified and inverted 180° by Q1. This signal is then coupled though the crystal, with another 180° phase shift, back to Q1's base. This action occurs at the parallel resonant frequency of the crystal.

The result is a stable, high frequency output signal suitable for those applications where a signal with constant frequency and amplitude is required. Several variations of this circuit exist. In one, a tuned tank is used as the collector load, replacing the RFC. Other variations include replacing the NPN transistor shown with a PNP type or with a field-effect transistor (FET). FETs are the subject of a later lesson.

The ratio of the capacitive reactances of C1 to C_C also determines the amount of regenerative feedback applied to the crystal, via the base of Q1. Increasing the value of C1, for example, would decrease its reactance, thus decreasing the feedback voltage applied to Q1. The amount of feedback reaching the crystal is, of course, a critical factor. Too little feedback results in weak or unstable oscillations, or even stalling. Too much feedback produces an unstable, distorted output and may overdrive the crystal, causing permanent damage.

Crystals are fragile devices which cannot be subjected to undue stress and strain. Electrically, the drive voltage and current must be kept to specified limits. Physically, care must be taken in the handling of crystals. They should not be dropped or subjected to extreme temperatures. Also, to avoid possible internal damage, the crystal's leads should always be heat-sinked during soldering.

Returning to the diagram of the Pierce crystal oscillator, the function of its components can now be discussed. Look at Figure 12.

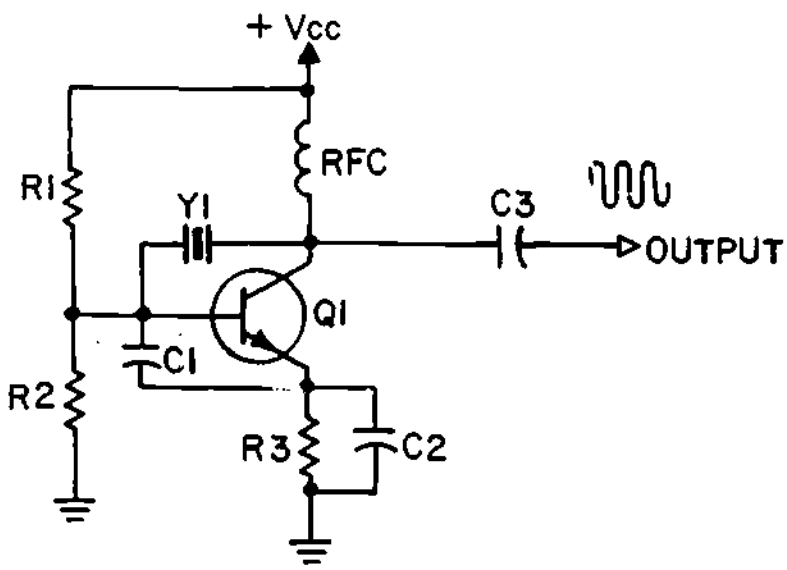


Figure 12

PIERCE XTAL OSCILLATOR

The Pierce oscillator utilizes the crystal's parallel, or anti-resonant, mode. An example of a crystal oscillator circuit which utilizes the series mode of operation, the tickler coil (Armstrong) crystal oscillator, is shown in Figure 13.

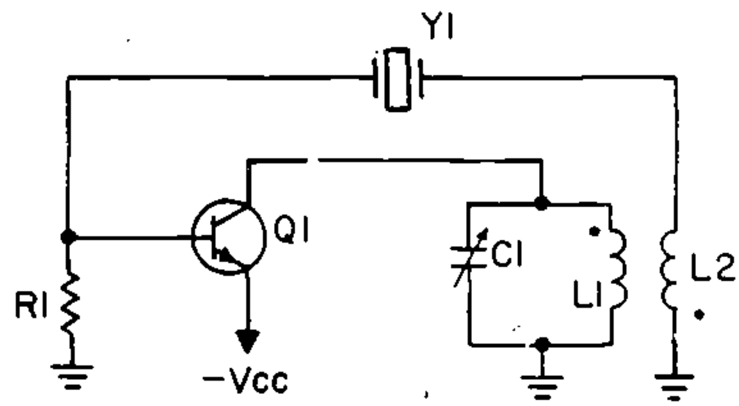


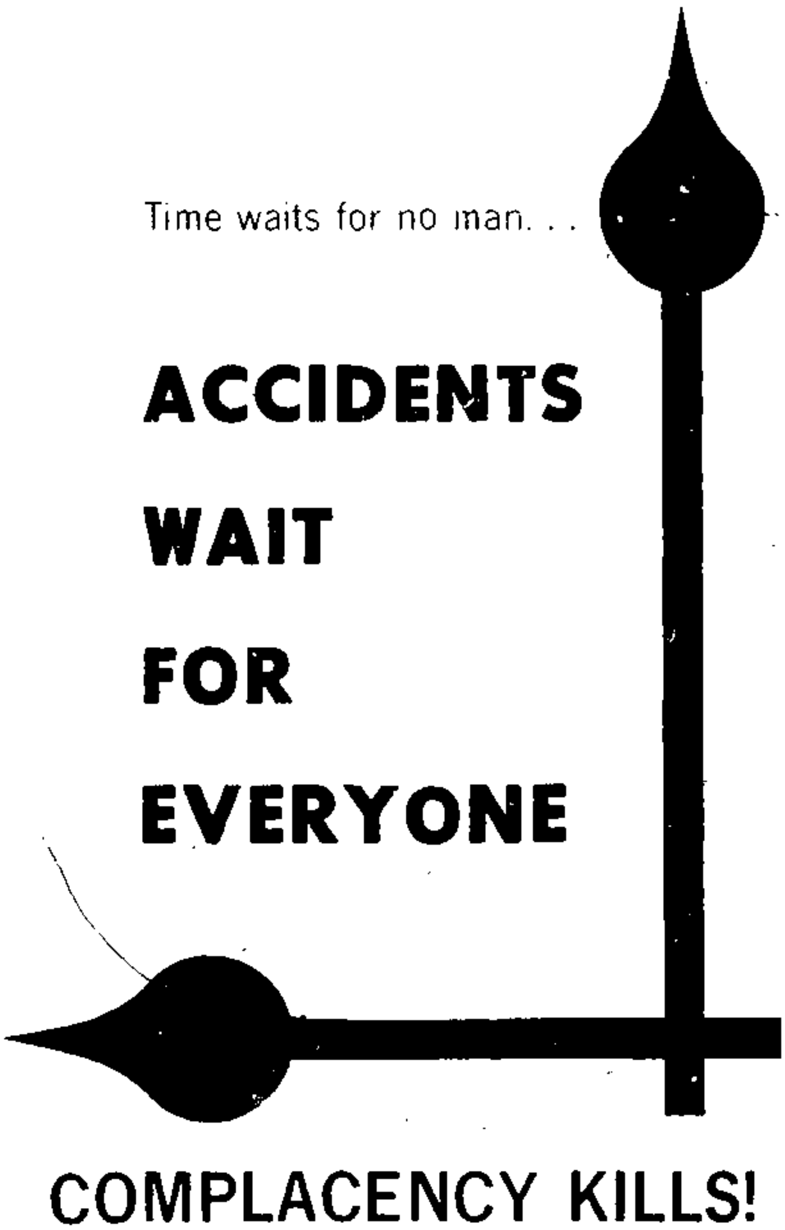
Figure 13

TICKLER COIL CRYSTAL OSCILLATOR

This circuit consists of a basic tickler coil oscillator with a crystal inserted in series with the feedback path.

When power is applied, current flows through R1 to V_{CC} providing forward bias to Q1. This enables the transistor to conduct and the oscillator to start. Tank circuit L1-C1 acts as the collector load and is tuned to the crystal's resonant frequency. L2 causes a 180° phase shift in the tank signal and couples a small amount of this RF energy to crystal Y1. The crystal operates as a series resonant circuit to a single frequency (its own natural resonant frequency), which it passes without phase shift to the base of Q1. In this way, a total 360° phase shift is achieved at the single frequency determined by Y1. This frequency becomes the operating frequency (f_0) of the oscillator. The crystal acts to filter out all frequencies except the desired oscillating frequency.

Frequency stability is the primary characteristic of crystal oscillators. Even so, the need to change or adjust the crystal's frequency sometimes exists. In some applications, exciting adjustments to the operating frequency are required. In other cases, aging can effect the crystal's shape and change its frequency slightly. Small adjustments to its operating frequency, called "pulling the crystal," can be made by placing a variable reactances either in series or in parallel with the crystal. This reactance may be inductive or capacitive, although commonly a small trimmer capacitor is used, such as the one (C4) shown in Figure 14.


Time waits for no man. . .
ACCIDENTS
WAIT
FOR
EVERYONE
COMPLACENCY KILLS!

261

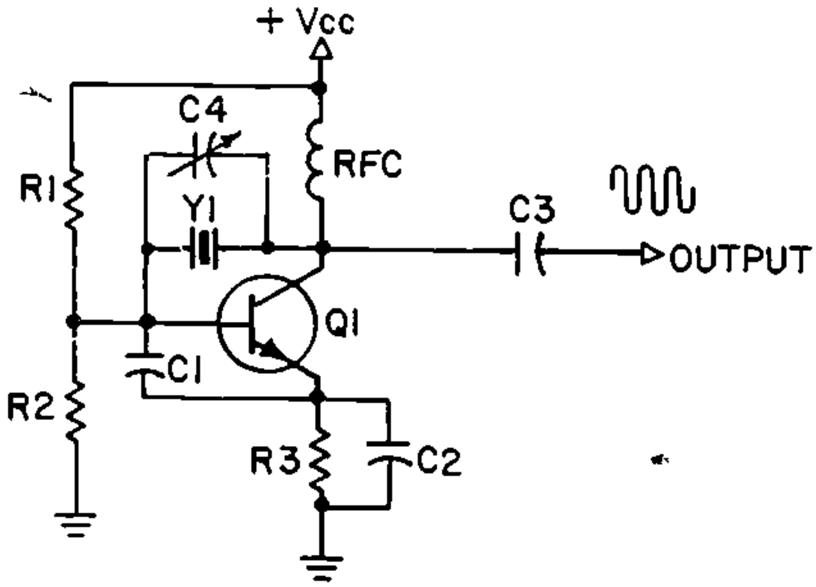


Figure 14

PIERCE CRYSTAL OSCILLATOR WITH TRIMMER

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK. IF YOU ANSWER ALL SELF-TEST ITEMS CORRECTLY, PROCEED TO THE LESSON TEST. IF YOU INCORRECTLY ANSWER ONLY A FEW OF THE PROGRESS CHECK QUESTIONS, THE CORRECT ANSWER PAGE WILL REFER YOU TO THE APPROPRIATE PAGES, PARAGRAPHS, OR FRAMES SO THAT YOU CAN PESTUDY THE PARTS OF THIS LESSON YOU ARE HAVING DIFFICULTY WITH. IF YOU FEEL THAT YOU HAVE FAILED TO UNDERSTAND ALL, OR MOST, OF THE LESSON, SELECT AND USE ANOTHER WRITTEN MEDIUM OR INSTRUCTION, AUDIO/VISUAL MATERIALS (IF APPLICABLE), OR CONSULTATION WITH THE LEARNING CENTER INSTRUCTOR, UNTIL YOU CAN ANSWER ALL SELF-TEST ITEMS ON THE PROGRESS CHECK CORRECTLY.